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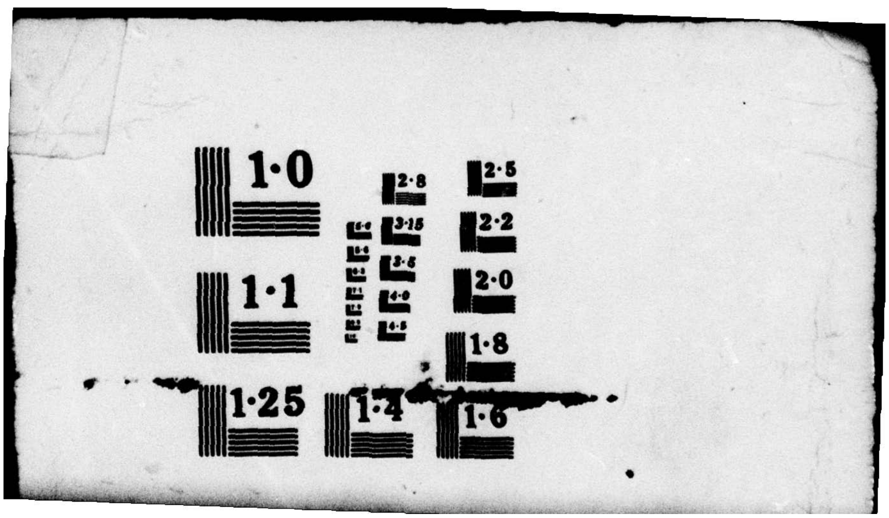
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EFFECTS OF THERMAL SPIKING ON GRAPHITE-EPOXY COMPOSITES

THE UNIVERSITY OF MICHIGAN
MECHANICAL ENGINEERING DEPARTMENT
ANN ARBOR, MICHIGAN 48109

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Alfred C. Loos

June 1979

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Tests were performed evaluating the effects of thermal spikes on the moisture absorption characteristics, the ultimate tensile strength, and the buckling modulus of Thornel 300/Fiberite 1034 composites. Measurements were made on unidirectional and angleply laminates, using different types of thermal spikes. A survey was also made of the existing data. This survey, together with the present data, indicate how thermal spikes affect the moisture absorption and the mechanical properties of different graphite-epoxy composites.

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FOREWORD

This interim report was submitted by Dr. George S. Springer and Mr. Alfred C. Loos of The University of Michigan, Mechanical Engineering Department, Ann Arbor, Michigan, under contract F33615-75-C-5165, Project 7340, Task 734003, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Marvin Knight, AFML-MBM, was the laboratory project monitor.

This report is for the project period March 1978 to March 1979. The work performed during the previous year (March 1977 to March 1978) was described in AFML-TR-78-86 A062554 "Effects of Moisture and Temperature on the Elastic Moduli of Composite Materials."

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SECTION I

INTRODUCTION

One of the questions in practical applications of composite materials is the degradation of the material due to exposure to a moist environment. Moisture absorbed by the material may have undesirable effects resulting in a reduction in mechanical properties. The environment may be especially damaging if the temperature is not constant but varies rapidly over a wide range. Sudden, large temperature changes, referred to as "thermal spikes", are encountered for example by aircraft flying at supersonic speeds.

Thermal spikes may alter significantly the moisture absorption as well as the mechanical properties of composite materials. For this reason, numerous investigators have been concerned with the effects of thermal spikes on material behavior. A summary of recent investigations is given in Table 1. Although the experimental results indicate that the changes caused by thermal spikes depend upon the characteristics of the spike, the dependence of material response on the thermal spike characteristics has not yet been explored in detail. The objective of this investigation was, therefore, to evaluate the relationships between material behavior and such thermal spike variables as maximum and minimum temperatures during the spike, rate of temperature increase and decrease, duration of the spike, and number of spikes. The effects of these variables on moisture content, the diffusion coefficient, the tensile strength, and the buckling modulus were examined for Thornel 300/Fiberite 1034 graphite-epoxy composites.

TABLE 1

SUMMARY OF EXPERIMENTAL DATA ON THE EFFECTS OF THERMAL SPIKES ON GRAPHITE EPOXY-COMPOSITES

Material	Reference	Absorption Behavior	Tensile Strength	Compression Strength	Shear Strength	Flexural Strength	Buckling Modulus	Tensile Modulus	Fatigue
T300/1034	Present work	N	N				N		
T300/934	Bohlmann-Derby [1]	N							
	Reinhart [2]	N							
T300/5208	McKague et al [3]	L							
	Kibler [4]	L							
	Augl [5]					N			
	Lundemo-Thor [6]		S						L
T300/5209	Stoecklin* [7]		S	N	N	S			
T300/2544	Stoecklin* [7]		S	S	S	S			
T400/2544	Trabocco-Stander* [8]		N-L	S	N				
AS/3501	Stoecklin* [7]		S	N	N	N			
	Trabocco-Stander* [8]			N					
AS/3501-5	Delasi-Whiteside [9]	N							
AS/X-2546	Browning-Hartness [10]					L			
HMS/339	Camahort et al [11]	N					N		
HMS/934	Camahort et al [11]	S					N		

Table 1 (Continued)

Material	Reference	Absorption Behavior	Tensile Strength	Compression Strength	Shear Strength	Flexural Strength	Buckling Modulus	Tensile Modulus	Fatigue
HMS/759	Camahort et al [11]	S						N	
HMS/3501	Camahort et al [11]	N						N	
HMS/X-2546	Browning-Hartness [10]					L			
HTS/3002	Trabocco-Stander* [8]				N				
HTS/4617	Browning-Hartness [10]		N	N	S				
HTS/ADX 516	Browning-Hartness [10]		N	N	S				
HTS/P 13 N	Browning-Hartness [10]		N	N	S				
HTS/X-911	Browning-Hartness [10]		N	N					
HTS/X-2546	Browning-Hartness [10]		N	L		L			
Modmor II/5206	Trabocco-Stander* [8]				N				
Narmco 2387(nr)	Browning-Hartness [10]		L						
ERL 2256(nr)	Browning -Hartness [10]		S						
ERLA 4617(nr)	Browning -Hartness [10]		L						
X2546(nr)	Browning-Hartness [10]		L						

N - negligible effect; S - small effect; L - large effect;
(nr) neat resin; * - weathering test

SECTION II

THERMAL SPIKES

Two thermal spiking sequences were employed, these being designated as "intermittent" spiking and "continuous" spiking. In intermittent spiking the material was remoisturized between subsequent spikes. In continuous spiking the material was exposed repeatedly to thermal spikes without being remoisturized between the spikes. The steps of each spiking sequence are described below.

1) Intermittent spiking

Intermittent spiking was performed in the following sequence (Figure 1)

a) The material was oven dried at 394 K.

b) The material was exposed to humid air (100% relative humidity, 366 K) until it became fully saturated.

c) The material was cooled to 297 K and was then exposed to one thermal spike.

d) The material was remoisturized in humid air (100% relative humidity, 366 K) until the maximum saturation level was reached as in step b.

Steps c and d were repeated until the required number of spikes were completed (spike N, Figure 1). Upon completion of the last (Nth) spike the following two steps were taken

e) The material was oven dried at 394 K.

f) The material was remoisturized in humid air (100% relative humidity, 366 K) until the maximum saturation level was reached.

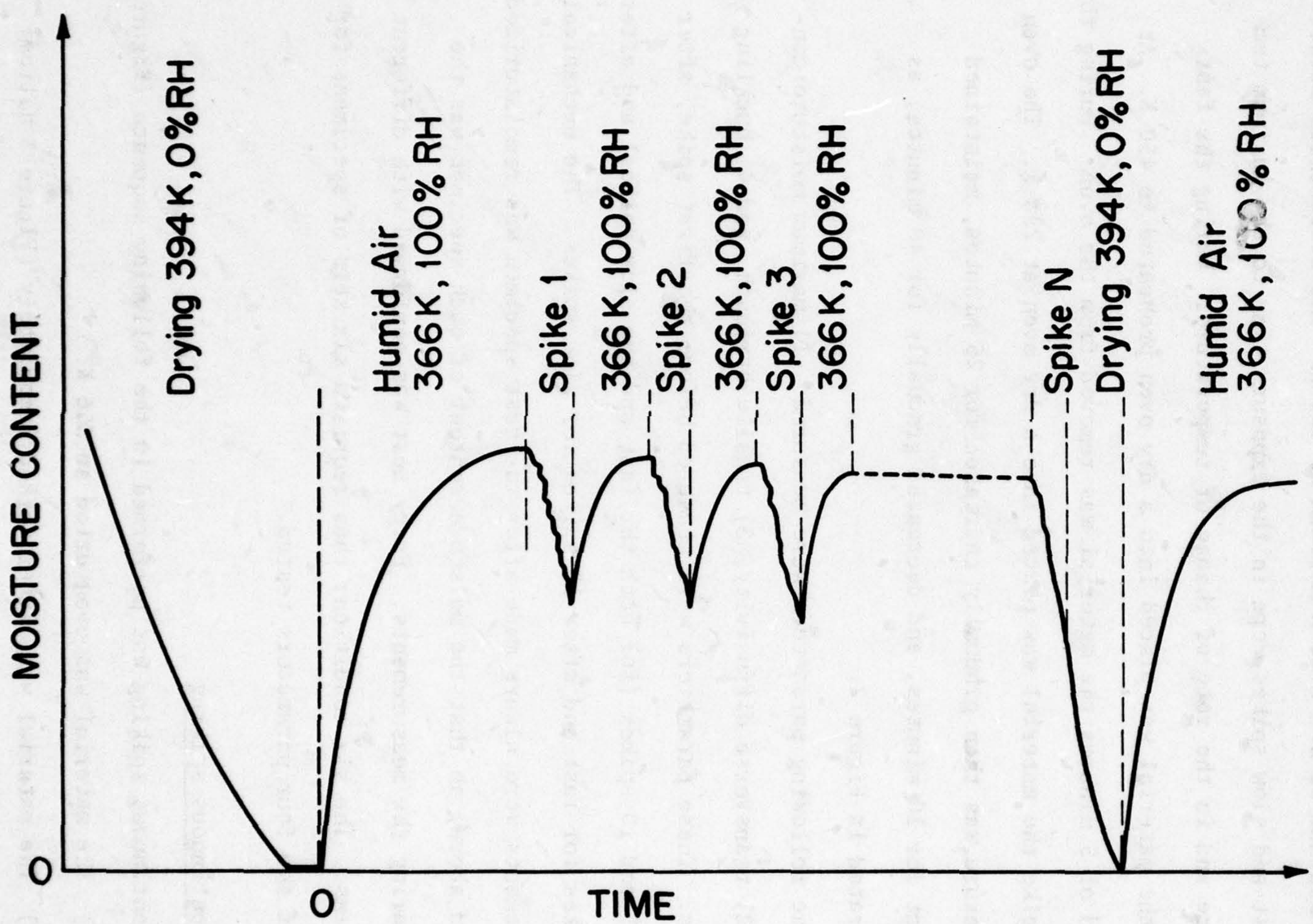

Figure 1. Intermittent Spiking Sequence

The above procedure was performed with either a "fast" spike or a "slow" spike (Figure 2). For both of these spikes the temperature ranged from a minimum of 297 K to a maximum of 450 K. The differences between the fast and slow spikes were in the exposure time to the maximum temperature and in the rate of change of temperature. During the fast spike the material was placed into a dry oven preheated to 450 K. At the end of 5 minutes the material was removed from the oven. During the slow spike the material was placed into a dry oven at 297 K. The oven temperature was then gradually increased for 25 minutes, maintained constant for 10 minutes, and decreased gradually for 40 minutes, as illustrated in Figure 2.

The following parameters were measured: 1) maximum moisture content, 2) transverse diffusivity, 3) tensile strength, and 4) buckling modulus. These parameters were measured before the first spike, after 1, 2, 5 and 10 spikes (for both the fast and the slow spikes) and after 20 spikes for fast and after 15 spikes for slow spikes. The mechanical measurements were always made after the test specimen was remoisturized (step d above) so that the moisture content of each specimen was the same during the measurements. Every test was performed with different specimens. The six conditions thus required six sets of specimens for each of the four parameters tested.

2) <u>Continuous spiking</u>

Continuous spiking was performed in the following sequence (Figure 3)

a) The material was oven dried at 366 K.

b) The material was either spiked immediately (Figure 3 bottom) or was immersed in humid air (100 percent relative humidity, 344 K) until the maximum saturation level was reached (Figure 3

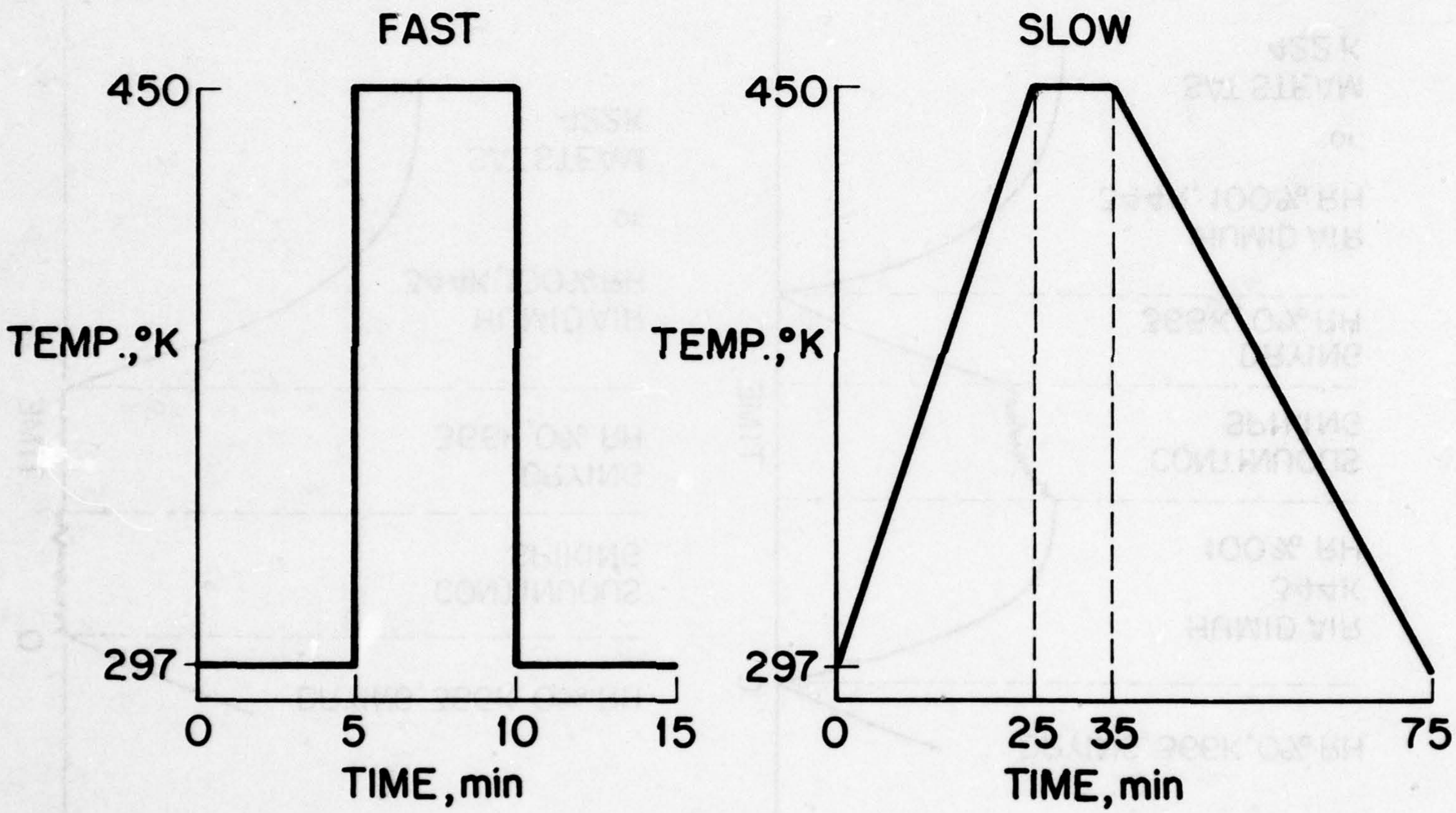

Figure 2. Thermal Spikes Used in Intermittent Spiking Program

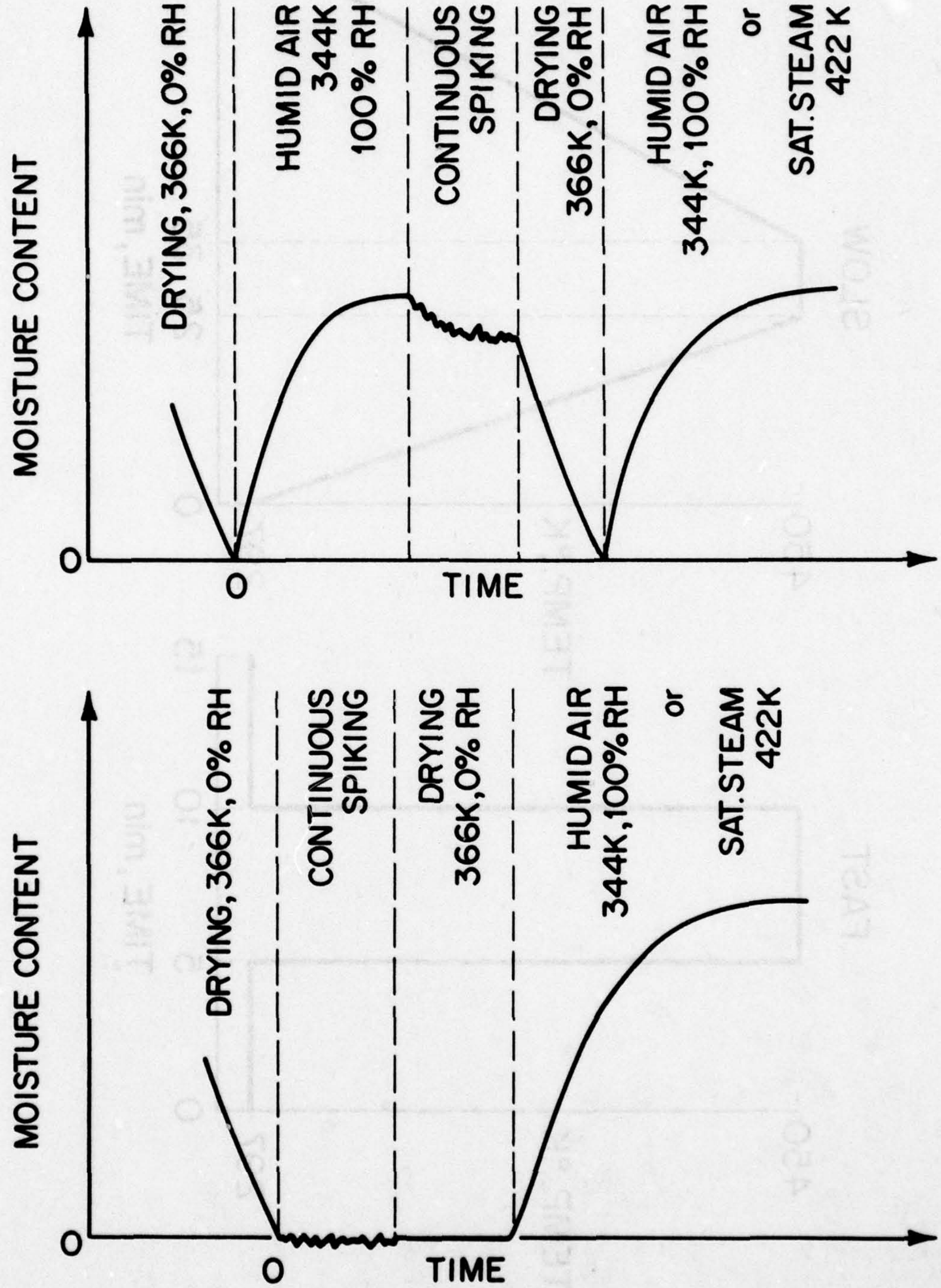

Figure 3. Continuous Spiking Sequence. Material at Maximum Saturation Level Prior to Spiking (Top). Material Dry Before Spiking (Bottom).

top). Thus, prior to being spiked the material was either dry or was fully saturated.

c) The material was spiked repeatedly in the manner described below.

d) The material was oven dried at 366 K.

e) The material was placed into an environmental chamber and remoisturized either in humid air (100% relative humidity, 344 K) or in saturated steam at 422 K.

The thermal spiking was accomplished by alternately placing the specimens into two reservoirs maintained at different temperatures. The specimens were kept for three minutes in each reservoir and were moved from one reservoir to the other without delay. Three constant temperature reservoirs at 195 K, 294 K, and 422 K were used to obtain the following temperature combinations

195 K —— 422 K

195 K —— 294 K

294 K —— 422 K

The specimens were spiked either once, five times, or twenty-five times. Different sets of specimens were used for each test. The two initial conditions (specimen dry or fully saturated), the three temperature combinations (see above), the three different numbers of spikes (1, 5 or 25) and the two saturation conditions after spiking (humid air or saturated steam) thus required 36 sets of specimens.

The weight change of the material as a function of time was measured before and after the spiking.

SECTION III

SPECIMENS IMMERSED IN SATURATED STEAM

In order to evaluate the effects of immersion in saturated steam, both unidirectional and /4 specimens were oven dried and then exposed to saturated steam at 422 K. The weight change of these specimens as a function of exposure time was monitored. In addition, the tensile strengths and buckling moduli of the specimens were measured before immersion and after 139, 278, 348, and 529 hours of exposure to saturated steam.

SECTION IV

EXPERIMENTAL

All data reported in this paper were obtained using specimens cut from 8 ply Thornel 300/Fiberite 1034 autoclave cured panels. The panels were fabricated from 30.5 cm prepreg (Fiberite Corp.) using standard layup and vacuum bagging procedures. The cure cycle used in manufacturing the panels is given in Appendix A. Both unidirectional (0°) and /4 specimens were used, the symbol /4 denoting a layup with $(0/\pm45/90)_s$ fiber orientations.

The specimens used for measuring weight gain as a function of time were 100 mm long, 12.7 mm wide, and 0.91 mm thick. The dimensions of the specimens used in the tensile tests are shown in Fig. 4. The buckling tests were made with 0.91 mm thick and 4.95 mm wide specimens, ranging in length from 56 to 173 mm.

The maximum moisture content M_m and the transverse diffusivity D were determined from the measured weight gain versus time curves according to the procedure described in ref. 12. The ultimate tensile strength and the buckling modulus were measured using a 10,000 lb capacity Instron machine (Model TTCLM 1-4) at a cross head speed of 1.27 mm min^{-1}. The buckling moduli were determined using the procedure given by Shen and Springer [13]. Both the tensile and the buckling tests were made at room temperature (297 K). Every data point presented in the following section is the average of three measurements.

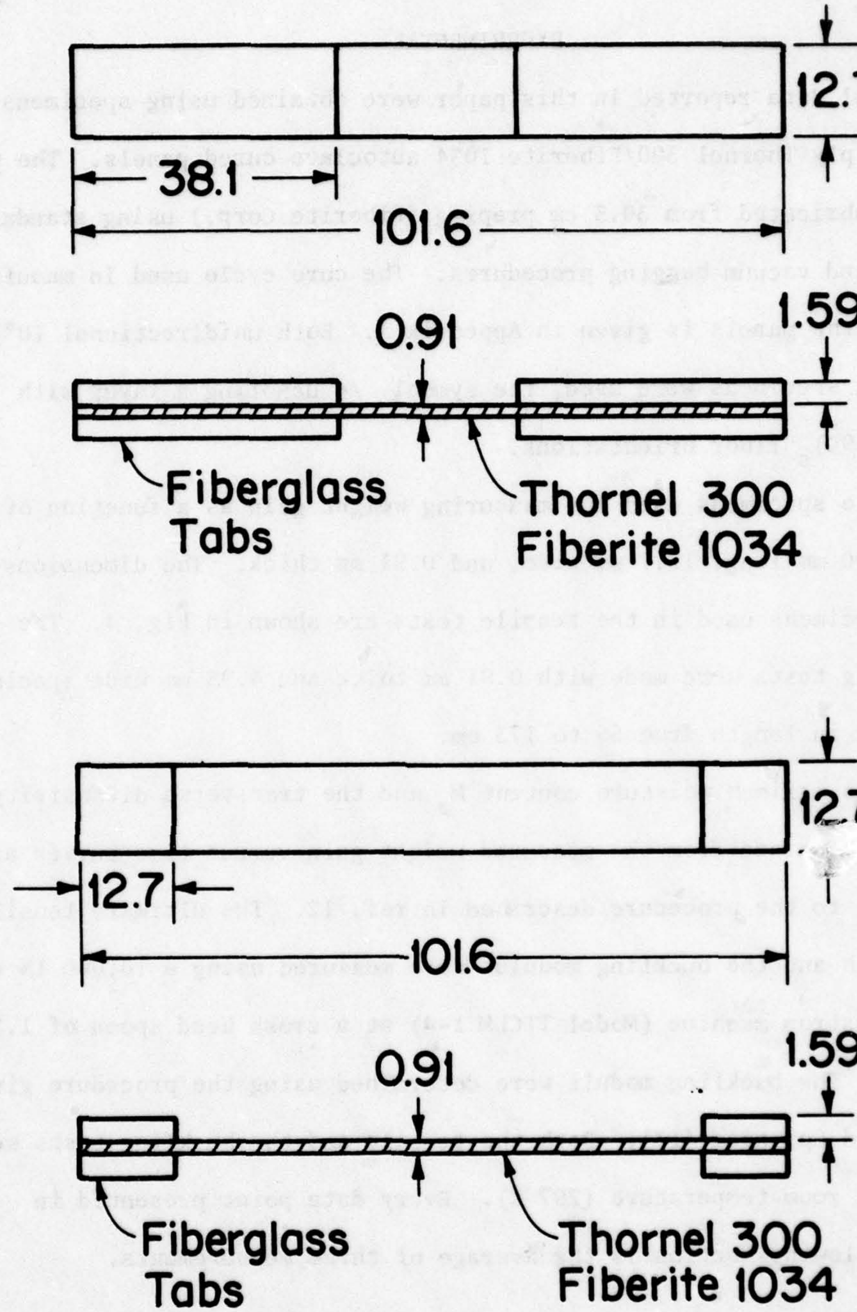

Figure 4. Geometry of Tensile Test Specimens, 0° Laminates (Top), π/4 Laminates (Bottom). (All Dimensions in mm.)

SECTION V

RESULTS

1) <u>Intermittent spiking</u>

The data obtained with intermittent spiking are presented in Figures 5-8. As is seen from Figure 5 the maximum moisture content M_m remained unchanged through 20 fast and 15 slow spikes. The transverse diffusivity D was also unaffected by the spiking (Figure 6). It is concluded, therfore, that the moisture absorption characteristics of Thornel 300/ Fiberite 1034 do not change appreciably with spiking, as long as the spiking conditions are within the limits of the present tests.

In Figures 9 and 10 photomicrographs of unidirectional and /4 specimens are shown after 20 fast and 15 slow spikes. The micrographs indicate that no cracks have developed in the microstructure of unidirectional and /4 specimens after 20 fast spikes (Figure 9) or in unidirectional specimens after 15 slow spikes (Figure 10, Left). The micrograph of the /4 specimen after 15 slow spikes ahows that cracks are present in the composite structure. However, these cracks did not seem to affect appreciably either M_m or D.

It is noted that the diffusivities of the unidirectional and the /4 composites are expected to be nearly the same [12]. The small differences in the observed diffusivities may have been due to unintentional differences in the curing processes of the two materials. Slight differences during curing may result in different diffusivites. This is illustrated in Figure 11, where the moisture contents of two sets of Hercules AS/3501-5 graphite epoxy specimens are compared. The two sets were from the same panel. The panel was post-cured in two sections, with both sections postcured simultaneously in the same oven. As can be seen the moisture contents (as well as M_m and D) for the two panels are

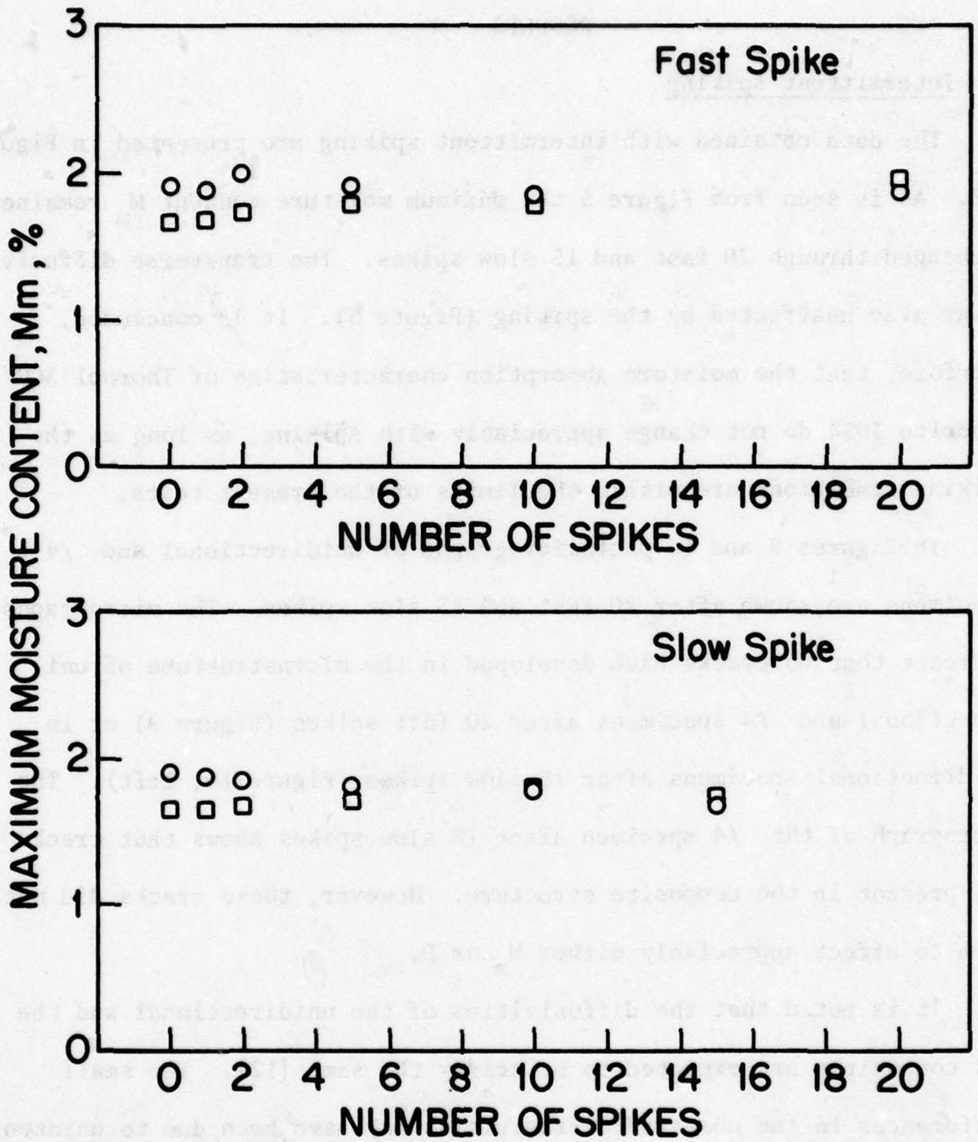

Figure 5. Maximum Moisture Content, Mm Versus Number of Intermittent Spikes, T300/Fiberite 1034. O-Unidirectional Laminates; □ - π/4 Laminates.

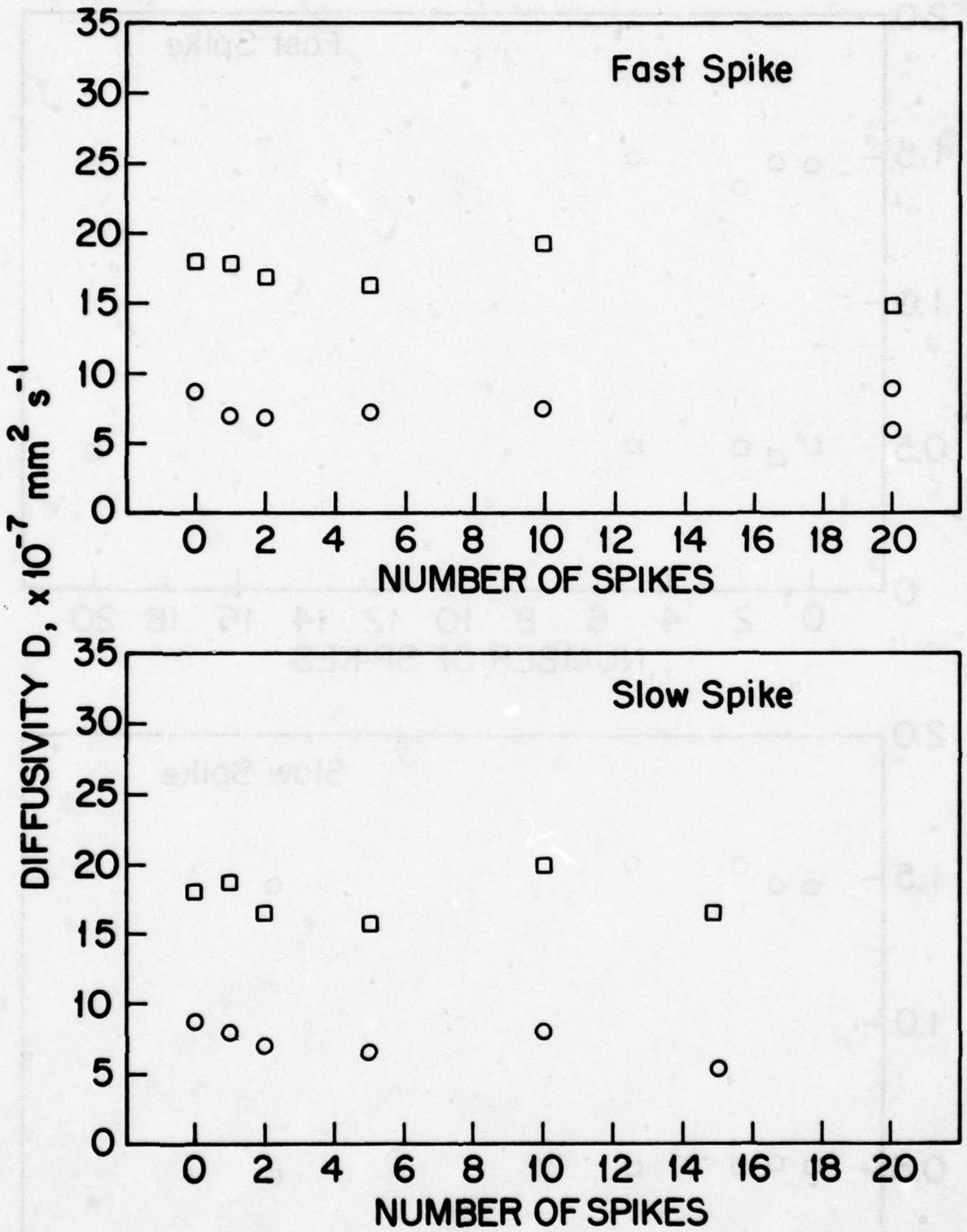

Figure 6. Transverse Diffusivity, D Versus Number of Intermittent Spikes, T300/Fiberite 1034. 0 - Unidirectional Laminates; □ - π/4 Laminates.

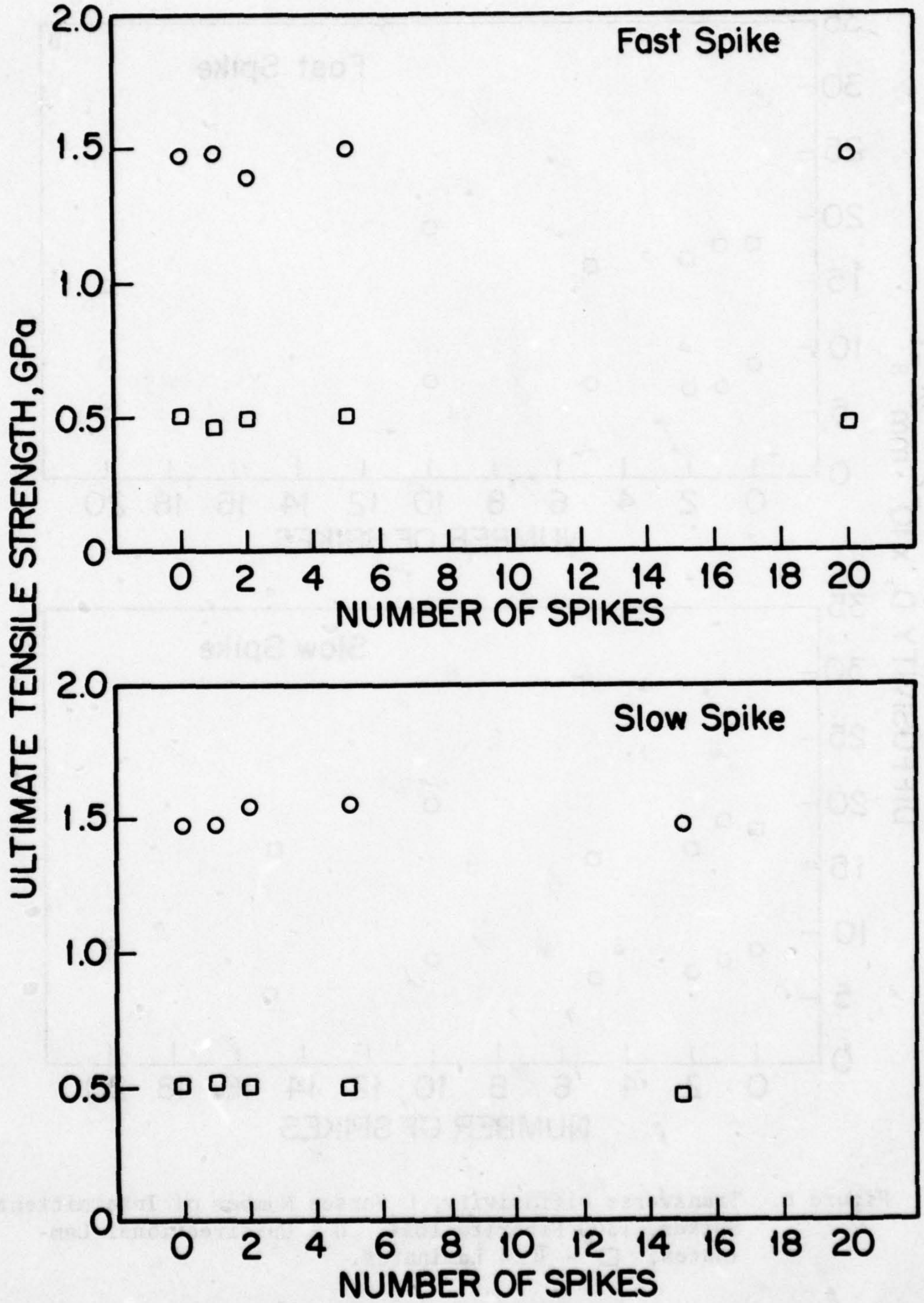

Figure 7. Ultimate Tensile Strength Versus Number of Intermittent Spikes, T300/Fiberite 1034. 0 - Unidirectional Laminates; □ - $\pi/4$ Laminates.

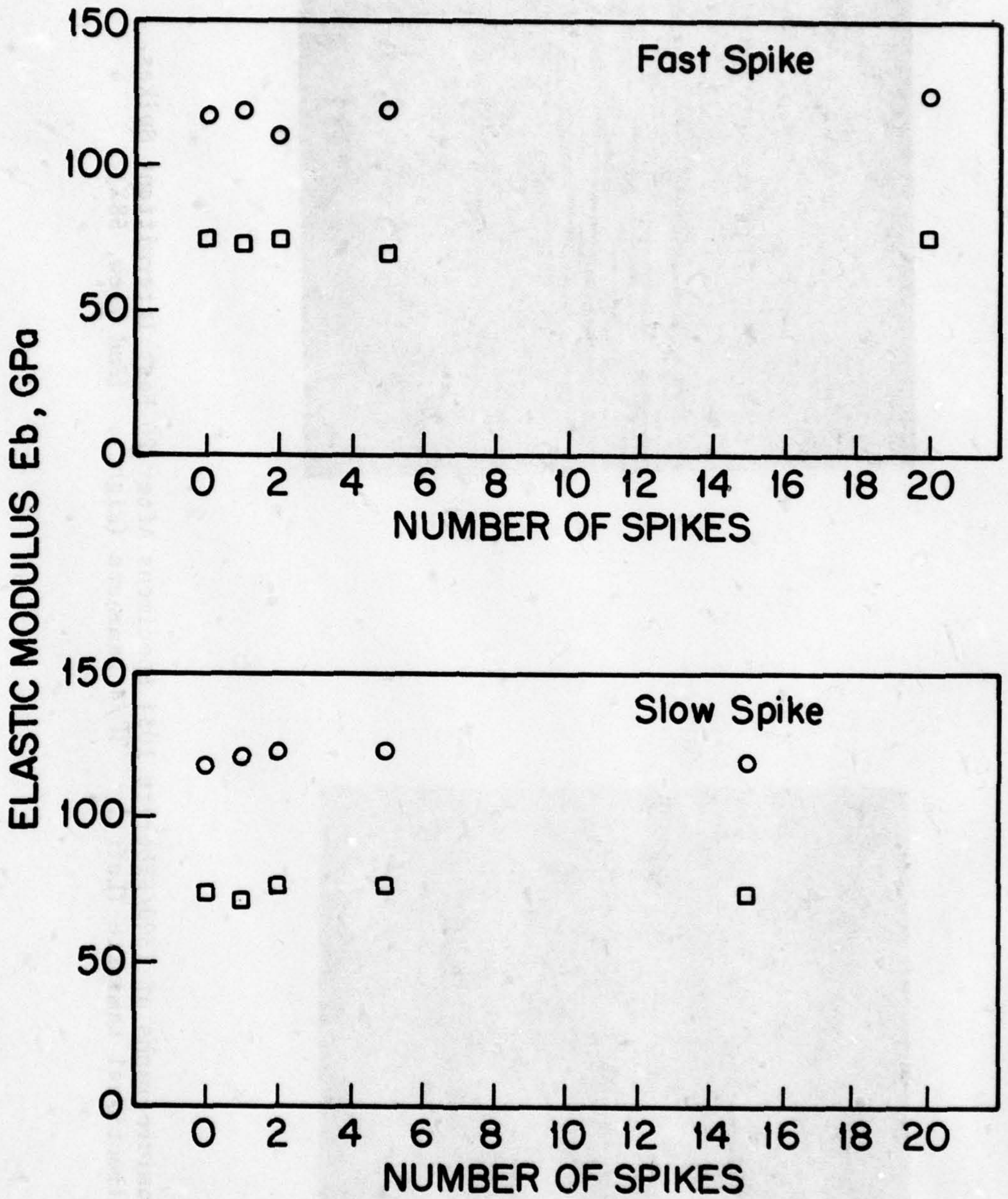

Figure 8. Elastic (Buckling) Modulus, E_b Versus Number of Intermittent Spikes, T300/Fiberite 1034. 0 - Unidirectional Laminates; □ - π/4 Laminates.

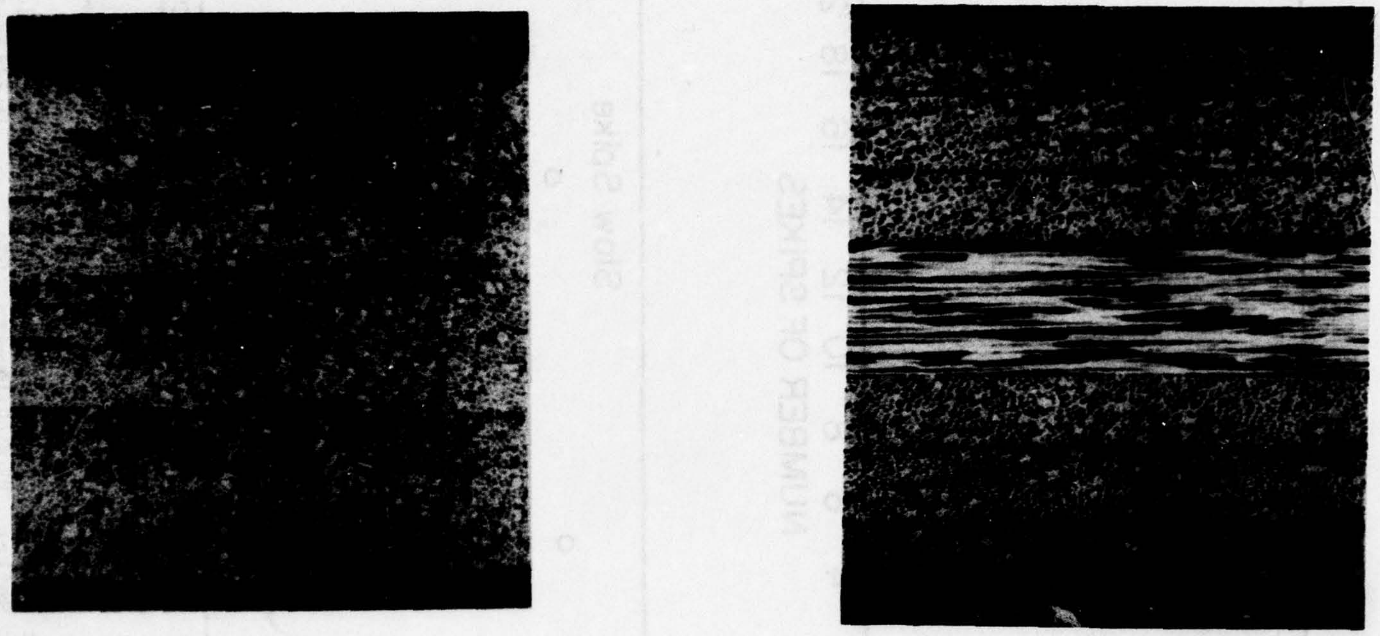

Figure 9. Photomicrographs of T300/Fiberite 1034 Specimens After 20 Fast Intermittent Spikes. Unidirectional Laminate (Left). $\pi/4$ Laminate (Right). (End View, 58X).

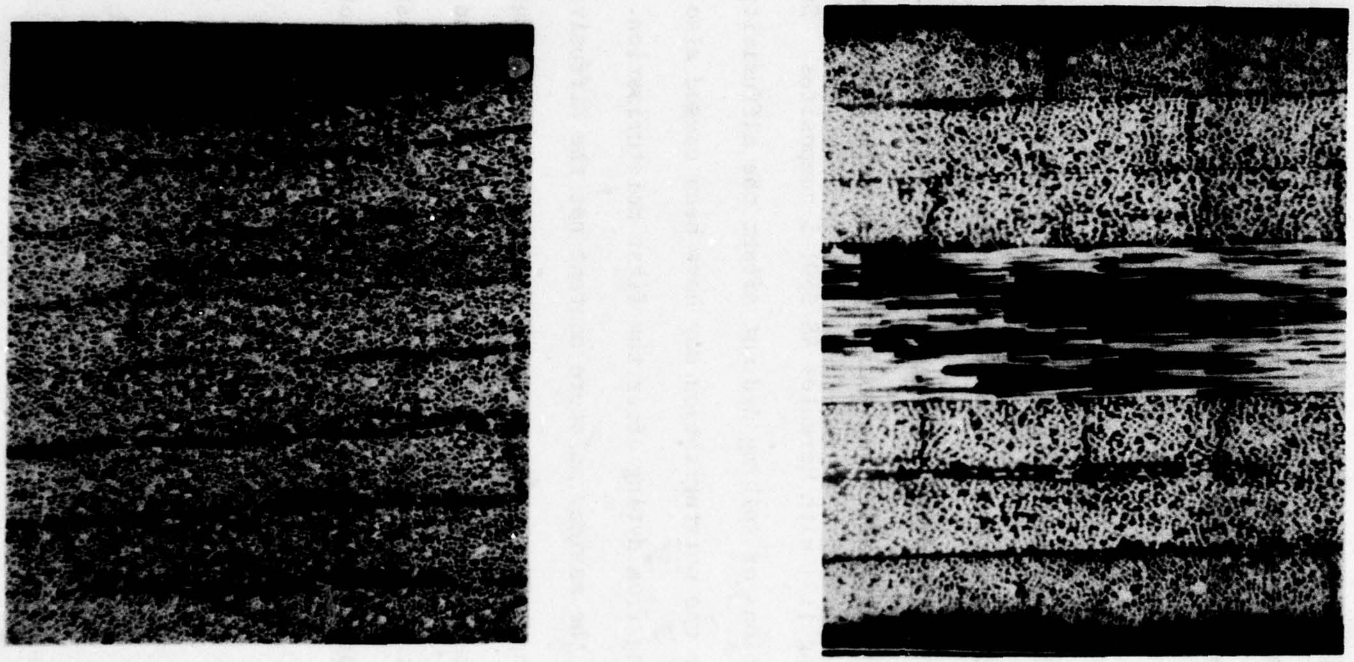

Figure 10. Photomicrographs of T300/Fiberite 1034 Specimens After 15 Slow Intermittent Spikes. Unidirectional Laminate (Left). $\pi/4$ Laminate (Right). (End View, 58X).

considerably different even though the curing conditions were ostensibly the same for both panels.

The higher diffusivites of the /4 specimens (see Figure 6) may also have been caused by moisture diffusion along the fiber-matrix interfaces. There are many more of these interfaces exposed to the environment around the edges of /4 specimens than around the edges of unidirectional specimens.

Although the diffusivity did not change with spiking, interestingly the diffusivity did increase 50 to 75 percent after the material was once moisturized and then dried. Changes in diffusivity (and also in maximum moisture content) after one moisturization were also observed by Whitney and Browning [14] with Hercules AS/3501-5 composites. Subsequent moisturizations or spiking did not affect the diffusivity. This increase in D after one moisturization may have been caused also by postcuirng resulting from dyting after the first moisturization.

Since neither the maximum moisture content not the diffusivity changed with spiking, the tensile strength and the buckling modulus were expected to remain constant too. The data in Figures 7 and 8 show this to be indeed the case. The spiking did not affect the tensile strength and the buckling modulus of either the unidirectional or the /4 composites.

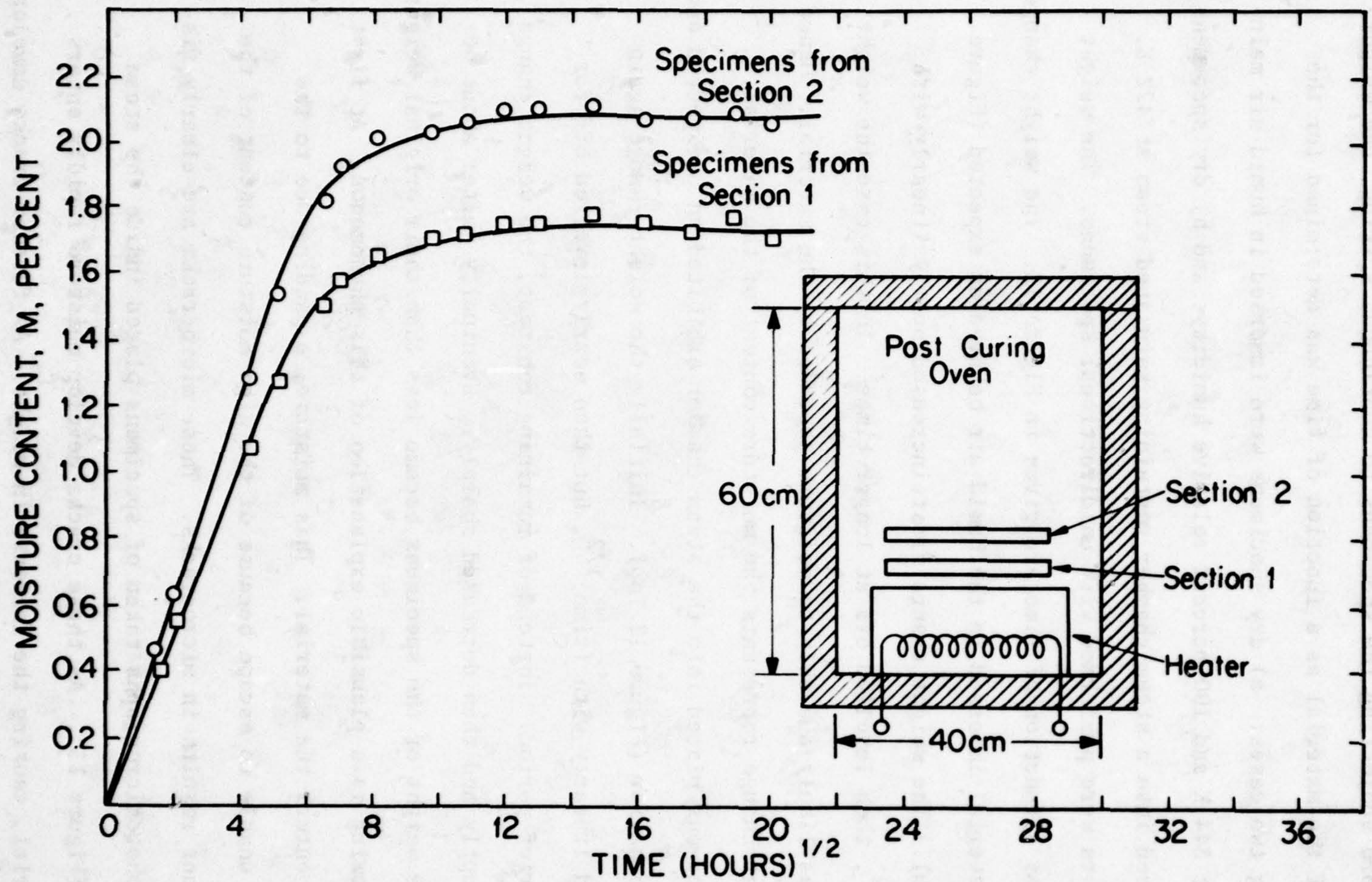

Figure 11. Moisture Absorption of Graphite AS/3501-5 Specimens Cut from Two Sections of the Same Panel, and Postcured in the Same Oven. Distance Between the Two Panels 0.5 cm. Temperature Monitored by Thermocouples Mounted on the Surfaces of Both Panels.

2) Weight change as a function of time

Before subjecting the specimens to continuous spiking, the weight change of the material as a function of time was determined for the following two cases: a) dry specimens were immersed in humid air maintained at 344 K and 100 percent relative humidity, and b) dry specimens were placed into a steam chamber containing saturated steam at 422 K. These tests were performed with unidirectional specimens. The weight changes as a function of time are given in Figure 12. The weight change of the material immersed in the humid air behaved as expected (Figure 12 Bottom). The weight change first increased nearly linearly with $(\text{time})^{1/2}$, then levelled off at longer times. In this case the weight change was likely due only to moisture absorbed by the material. Hence the weight change represents the moisture content of the material.

Specimens placed into the steam chamber exhibited an unexpected and unusual behavior (Figure 12 Top). Initially the weight change again increased linearly with $(\text{time})^{1/2}$, but then nearly levelled off for only a brief period. Instead of remaining constant, the weight change rose abruptly and then decreased sharply. Eventually (after about 60 days) the weight of the specimens became less than their original weight. The following is a plausible explanation of this phenomenon. At first moisture enters the material. This moisture, expanding due to the heat but unable to escape because of the high moisture content of the environment results in microcracks. These microcracks are clearly visible in photomicrographs taken of specimens placed inside the steam chamber (Figure 13). As these cracks develop moisture rapidly enters the material, causing the increase in weight. As further cracks develop,

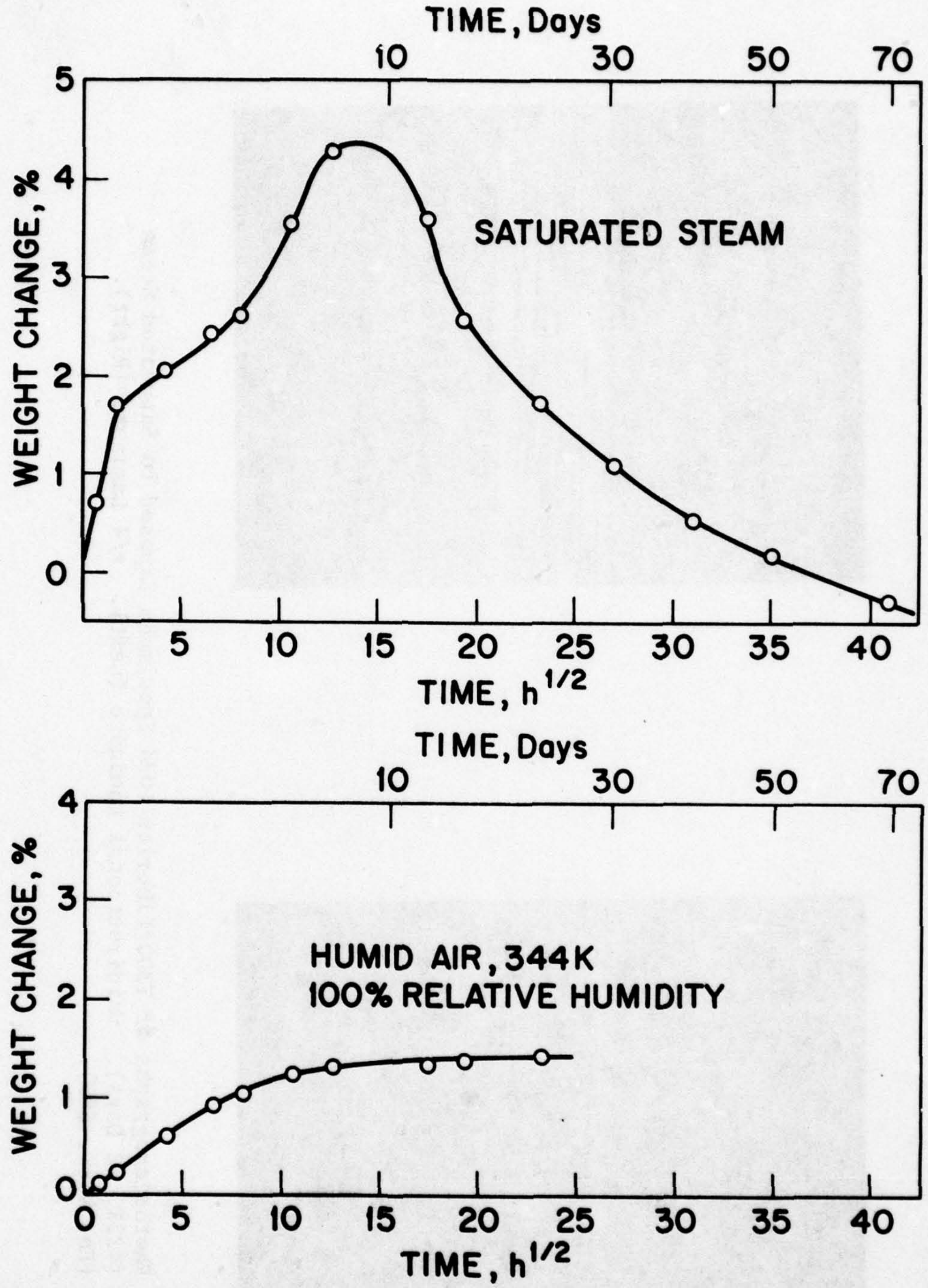

Figure 12. Weight Change as a Function of Time of Unidirectional T300/Fiberite 1034 Specimens Immersed in Saturated Steam (Top) or in Humid Air (Bottom). O - Data, ——— Fit to Data.

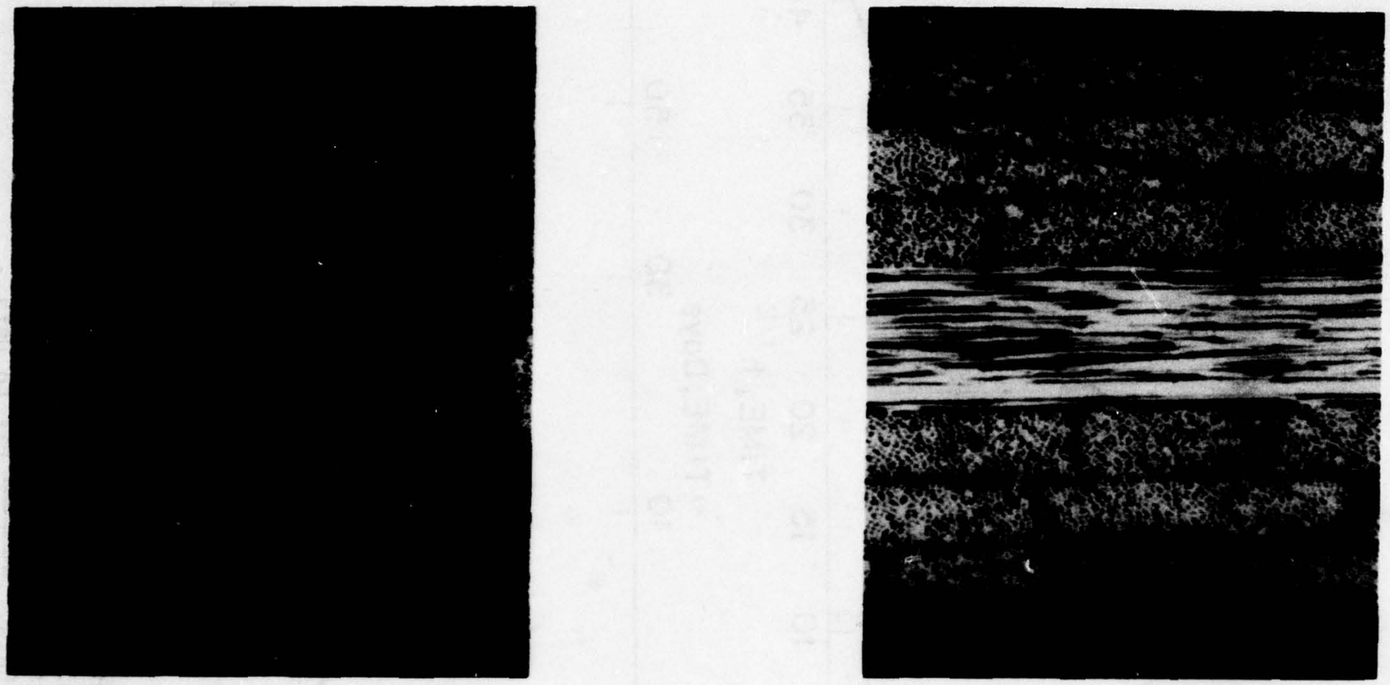

Figure 13. Photomicrographs of T300/Fiberite 1034 Specimens Exposed to Saturated Steam (422K, 22 Days). Unidirectional Laminate (Left). $\pi/4$ Laminate (Right). (End View, 58X).

material, most likely in the form of resin particles, is actually lost. During this material loss moisture may still be entering the material. As long as the moisture gain is greater than the material loss the weight of the specimen increases. Once the weight of the lost material exceeds the weight of the absorbed moisture the weight of the specimen decreases. Of course when material is lost the measured weight change no longer corresponds to the moisture content of the material.

It is important to note that the phenomenon shown in Figure 12 Top and described above has been observed to occur only when the environment is both at a high temperature and at a high moisture content. Even fully saturated specimens do not exhibit such behavior when placed into a high temperature but dry environment. If the ambient moisture content is low the moisture can apparently diffuse out of the material at a rate which is sufficient to prevent the build-up of crack-producing stresses. This is a useful observation since the ambient moisture content (relative humidity) is usually low at high temperatures.

3) Continuous spiking

The weight changes as a function of time after one, five, or twenty-five continuous spikes are presented in Figures 14-17. For comparison the weight change as a function of time in the absence of spikes is also included in these figures (solid lines). Similar to intermittent spiking (see Section VI), continuous spiking did not seem to affect the moisture absorption characteristics of the material. The weight change exhibited the same characteristics regardless of whether or not the specimens were spiked. This was the case even when the material was placed in the steam chamber after spiking (Figures 16-17). The increase and

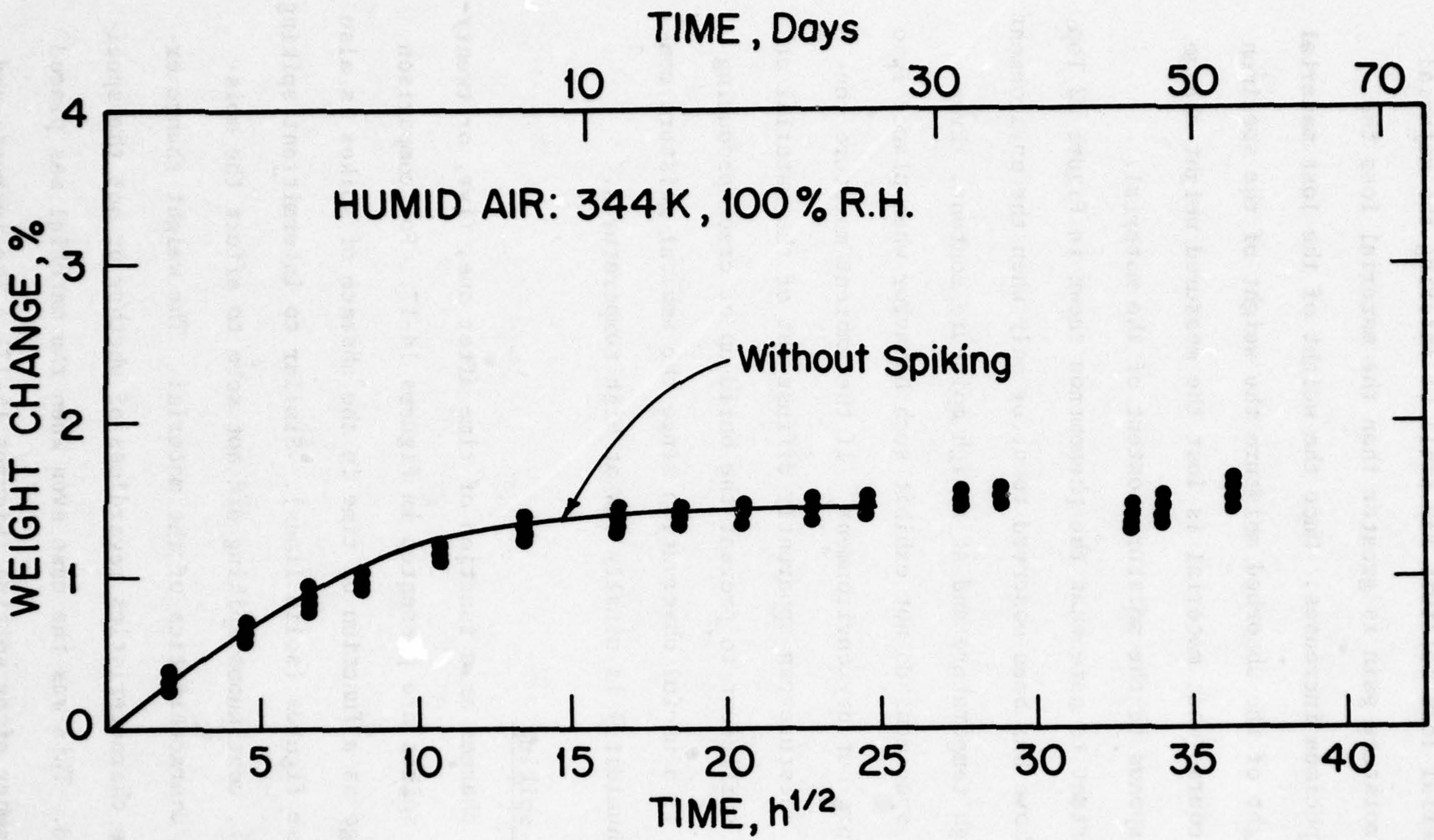

Figure 14. Weight Change as a Function of Time of Unidirectional T300/Fiberite 1034 Specimens Immersed in Humid Air After Continuous Spiking. Specimens Were Dry Before Spiking (see Figure 3, Bottom). ● - Data for Specimens Spiked 1, 5, or 25 Times Between the Temperatures 195 K to 422 K, 195 K to 294 K, or 294 K to 422 K; Solid line Represents Weight Change of Unspiked Specimens.

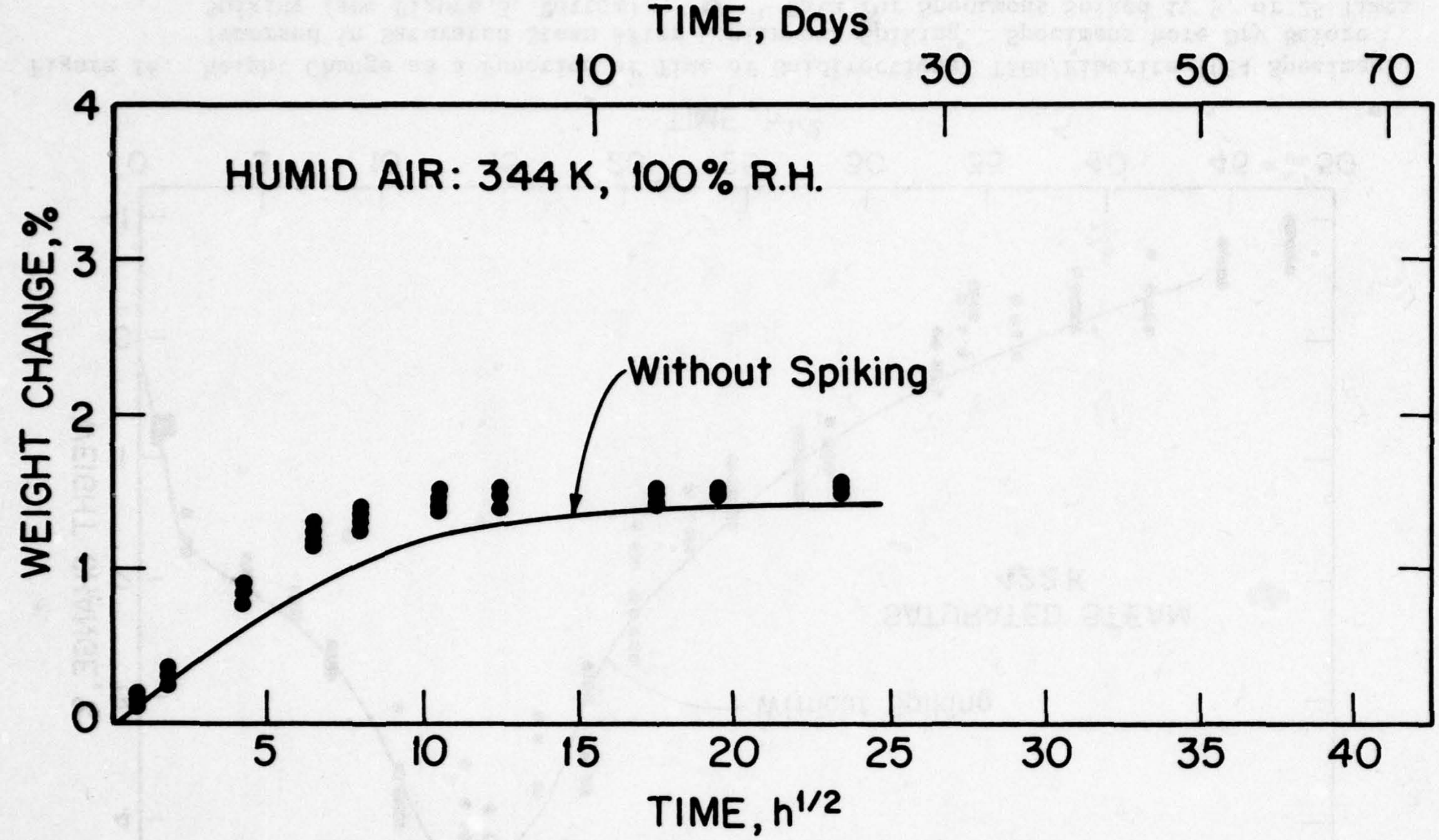

Figure 15. Weight Change as a Function of Time of Unidirectional T300/Fiberite 1034 Specimens Immersed in Humid Air After Continuous Spiking. Specimens Were Fully Saturated at 344 K, 100% Relative Humidity Before Spiking (see Figure 3, Top). ● - Data for Specimens Spiked 1, 5, or 25 Times Between the Temperatures 195 K to 422 K, 195 K to 294 K, or 294 K to 422 K; Solid Line Represents Weight Change of Unspiked Specimens.

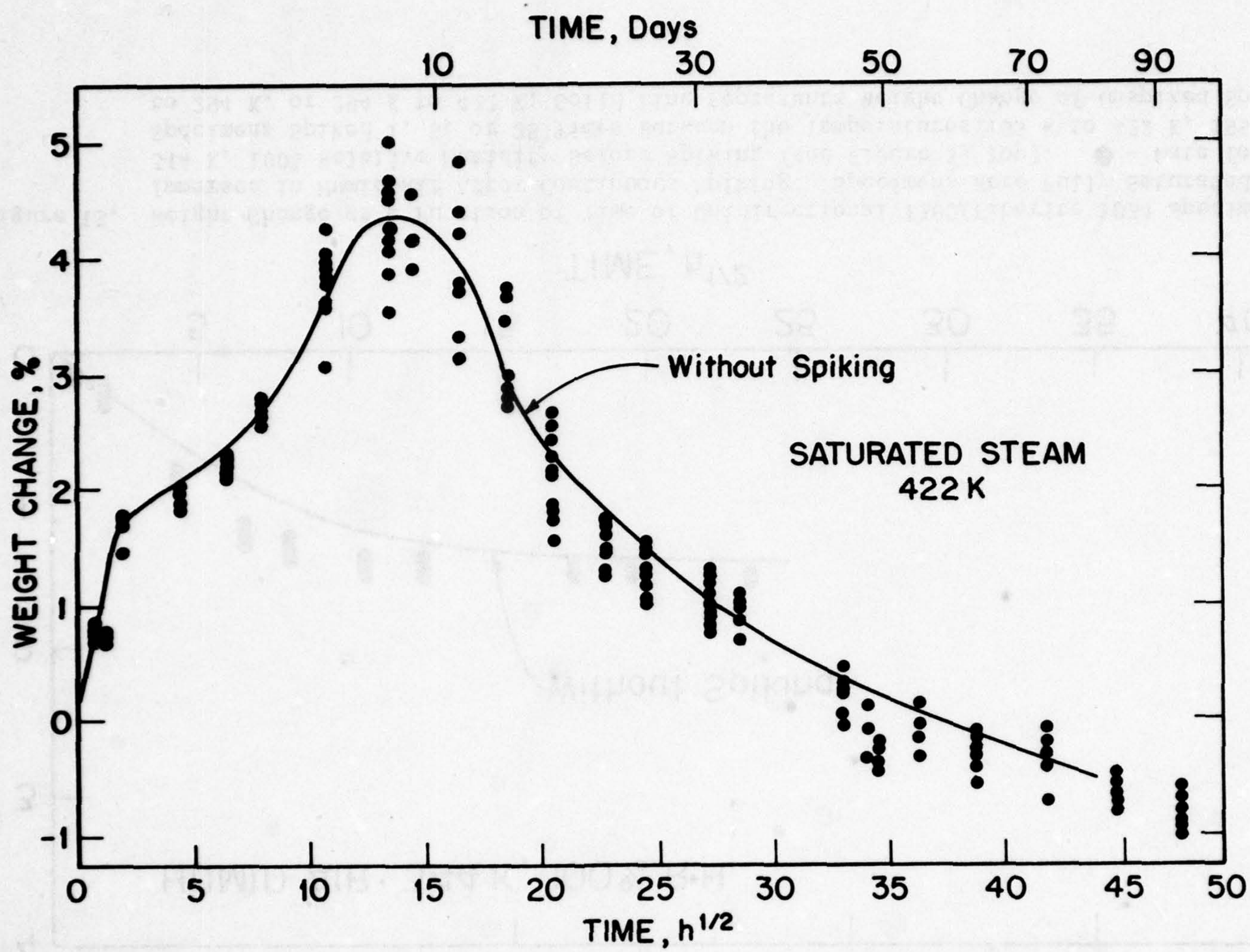

Figure 16. Weight Change as a Function of Time of Unidirectional T300/Fiberite 1034 Specimens Immersed in Saturated Steam After Continuous Spiking. Specimens Were Dry Before Spiking (see Figure 3, Bottom). ● - Data for Specimens Spiked 1, 5, or 25 Times Between the Temperatures 195 K to 422 K, 195 K to 294 K, or 294 K to 422 K; Solid Line Represents Weight Change of Unspiked Specimens.

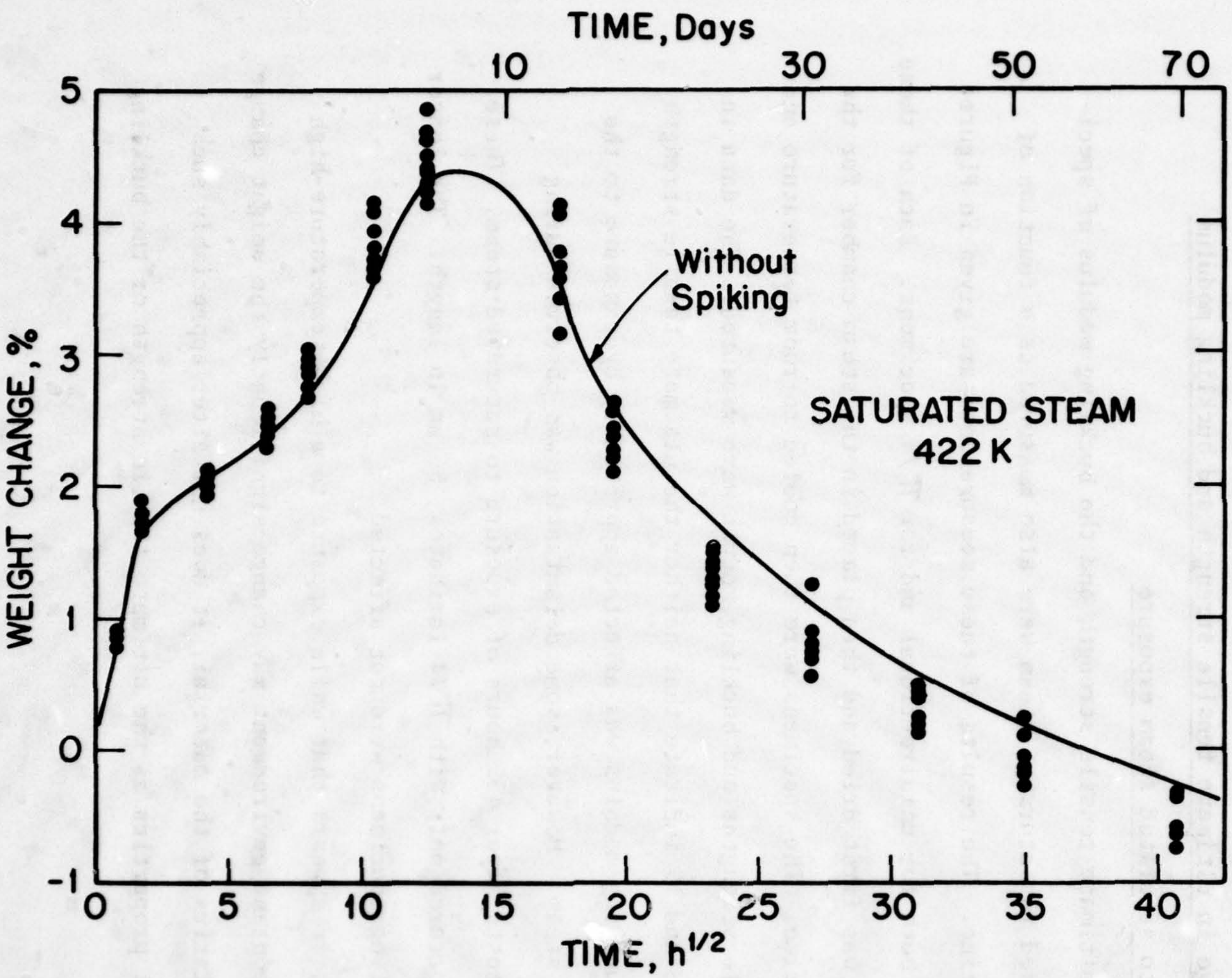

Figure 17. Weight Change as a Function of Time of Unidirectional T300/Fiberite 1034 Specimens Immersed in Saturated Steam After Continuous Spiking. Specimens Were Fully Saturated at 344 K, 100% Relative Humidity Before Spiking (see Figure 3, Top). ● - Data for Specimens Spiked 1, 5, or 25 Times Between the Temperatures 195 K to 422 K, 195 K to 294 K, or 294 K to 422 K; Solid Line Represents Weight Change of Unspiked Specimens.

subsequent decrease of the weight in this case was not caused by the spiking but by exposure to saturated steam, as discussed in the previous section.

4) <u>Change in ultimate tensile strength and buckling modulus due to saturated steam exposure</u>

The ultimate tensile strength and the buckling modulus of specimens exposed to saturated steam were also measured as a function of exposure time. The results of these measurements are given in Figures 18 and 19 both for unidirectional and for $\pi/4$ specimens. Each of these specimens was first dried and then placed in the steam chamber for the required time. The specimens were then cooled to room temperature and the tensile strengths and buckling moduli were measured. The data in Figures 18 and 19 indicate that neither the ultimate tensile strength nor the buckling modulus was affected appreciably by exposure to the saturated steam. However, some delamination was observed during buckling tests after 435 hours of exposure to saturated steam. These failures occured only with $\pi/4$ laminates, 56 mm in length. The longer $\pi/4$ buckling specimens were not affected.

Thus, it appears that while exposure to a high temperature-high moisture content environment may change significantly the weight change characteristics of the material, it does not alter appreciably such mechanical properties as the ultimate tensile strength or the buckling modulus.

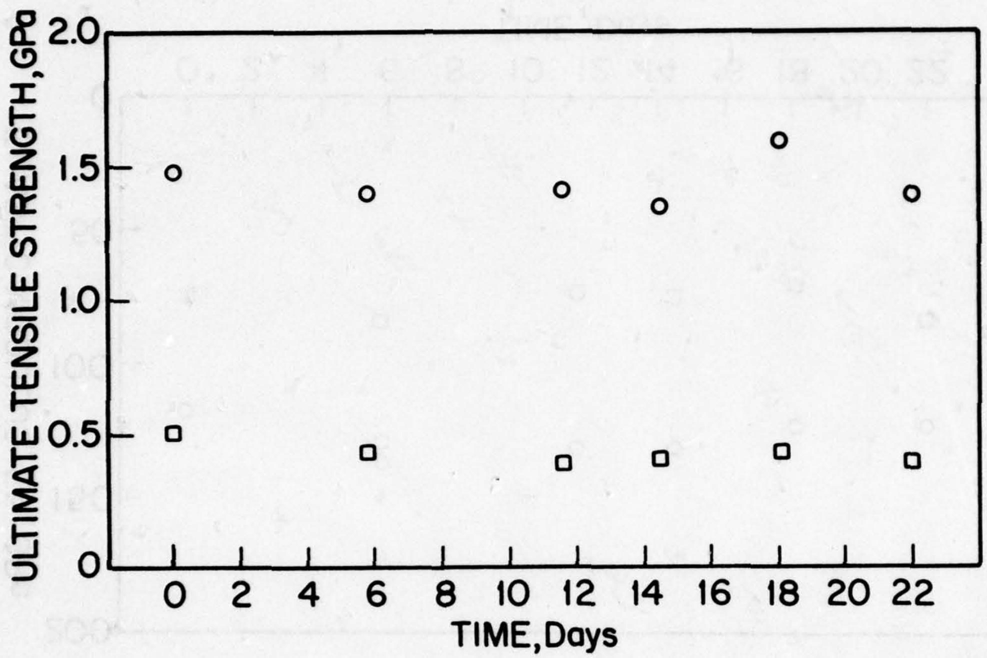

Figure 18. Ultimate Tensile Strength of T300/Fiberite 1034 as a Function of Exposure Time to Saturated Steam at 422 K. O - Unidirectional Laminates; □ - $\pi/4$ Laminates.

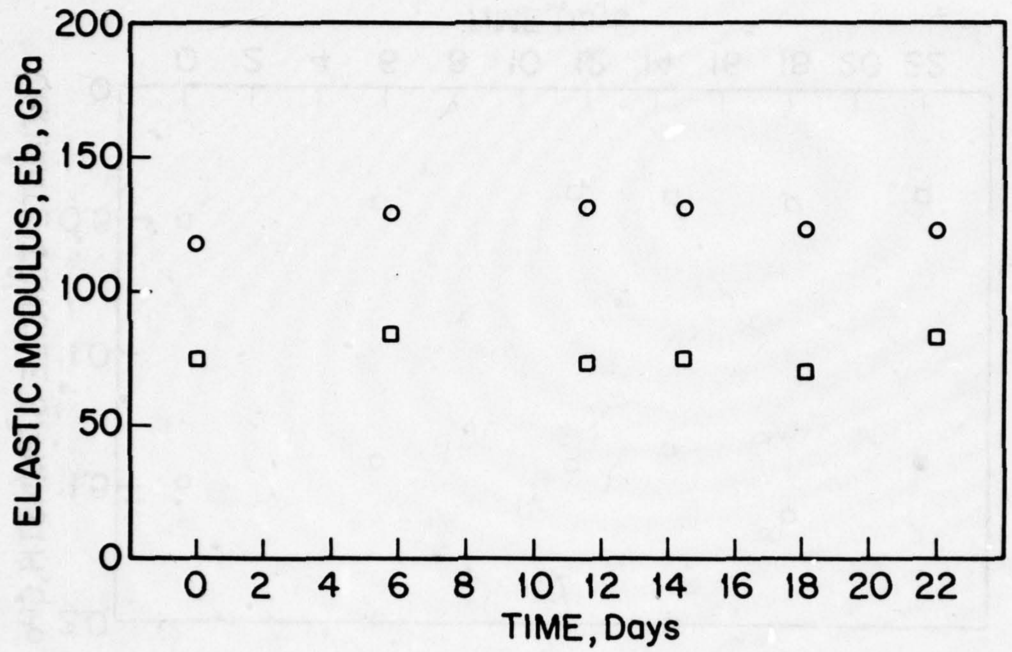

Figure 19. Elastic (Buckling) Modulus of T300/Fiberite 1034 as a Function of Exposure Time to Saturated Steam at 422 K. O - Unidirectional Laminates; □ - $\pi/4$ Laminates.

SECTION VI

CONCLUSIONS

The following general conclusions can be drawn on the basis of the present data, obtained with Thornel 300/Fiberite 1034 graphite epoxy composites

1) Thermal spiking does not change significantly the moisture absorption characteristics of the material as represented by the moisture content as a function of time, the maximum moisture content, and the transverse diffusivity.

2) Thermal spiking does not reduce either the tensile strength or the buckling modulus of unidirectional or $\pi/4$ laminates.

3) Immersion in 422 K saturated steam changes considerably the moisture absorption characteristics of the material causing cracking and, subsequently, material loss.

4) Long term (up to 20 days) immersion in 422 K saturated steam does not reduce either the ultimate tensile strength or the buckling modulus of either unidirectional or $\pi/4$ laminates.

The above conclusions apply only to Thornel 300/Fiberite 1034 composites. Examination of the data available for other graphite epoxy composites (see Table 1) provides the following additional information

5) The effect of thermal spiking depends on the composition of the material. Some graphite-epoxy composites are affected more by thermal spiking than T300/1034. The moisture absorption characteristics of T300/5208 laminates seem to be affected particularly by thermal spiking.

6) In most cases the mechanical properties of the material are not reduced significantly by thermal spiking. Fiber dominated properties seem to be especially insensitive to thermal spiking.

APPENDIX A

AUTOCLAVE CURE CYCLE FOR T300/1034

1. Vacuum Bag-insert layup into autoclave at room temperature.
2. Apply full vacuum and contact pressure.
3. Raise temperature to 250°F at 3°F per minute.
4. Hold at 250°F for 15 minutes. Apply 100 psi.
5. Hold at 250°F and 100 psi for 45 minutes.
6. Raise temperature to 350°F.
7. Hold at 350°F for 2 hours.
8. Cool under pressure to below 175°F.

APPENDIX B

DATA SUMMARY

This appendix includes the results of the intermittent spiking tests. Moisture content versus time curves for T300/Fiberite 1034 composites are shown on Figures B.1 through B.12 for unidirectional specimens and on Figure B.13 through B.24 for $\pi/4$ specimens.

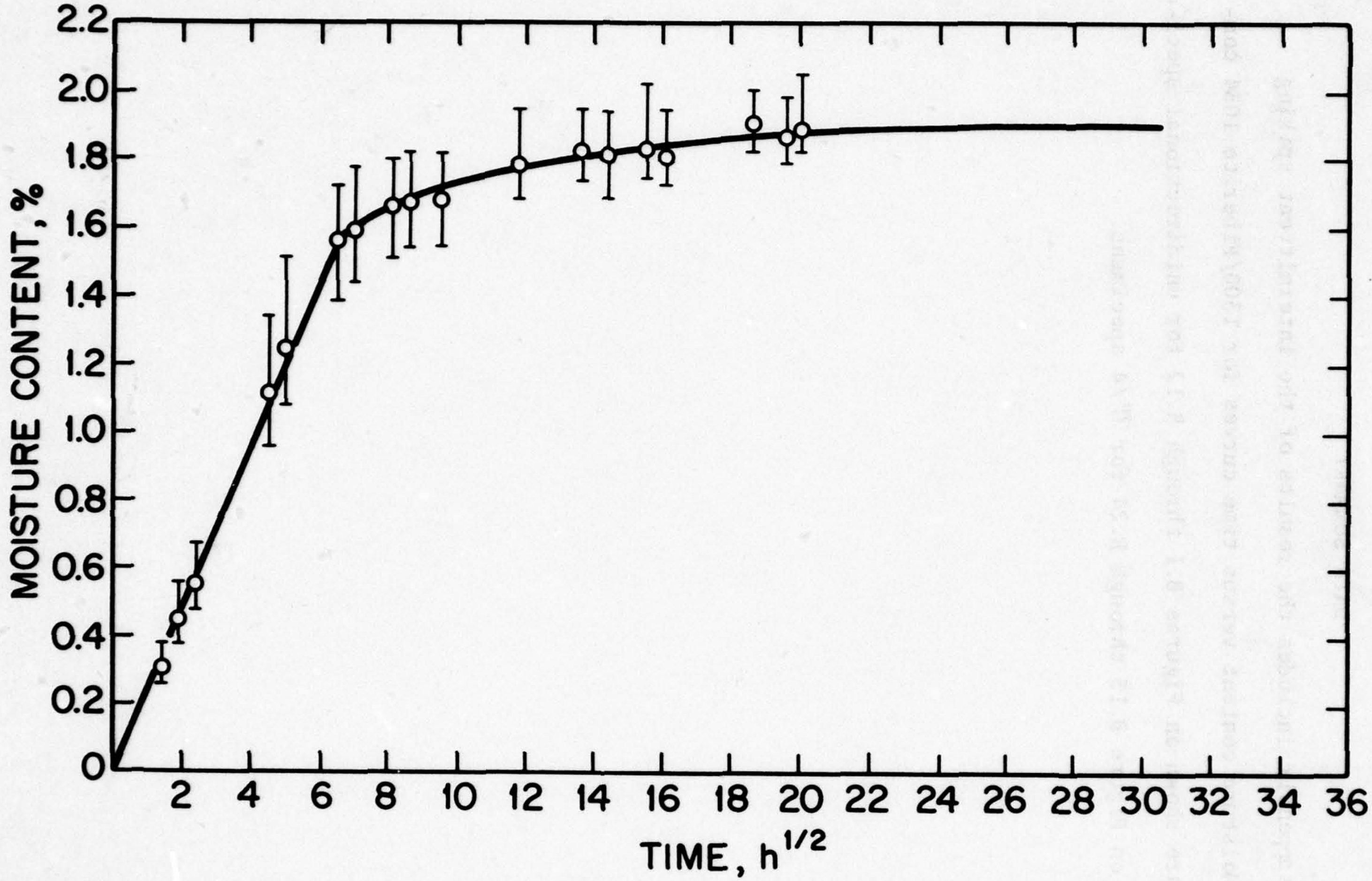

Figure B.1 Moisture Content Versus Exposure Time of Unidirectional T300/Fiberite 1034 Composites Exposed to 336 K Air at 100% Relative Humidity. Specimens Initially Dry. No Spiking. Circles Represent the Average of Three Data Points. Bars Represent Spread in Data. Solid Line is Fit to Data.

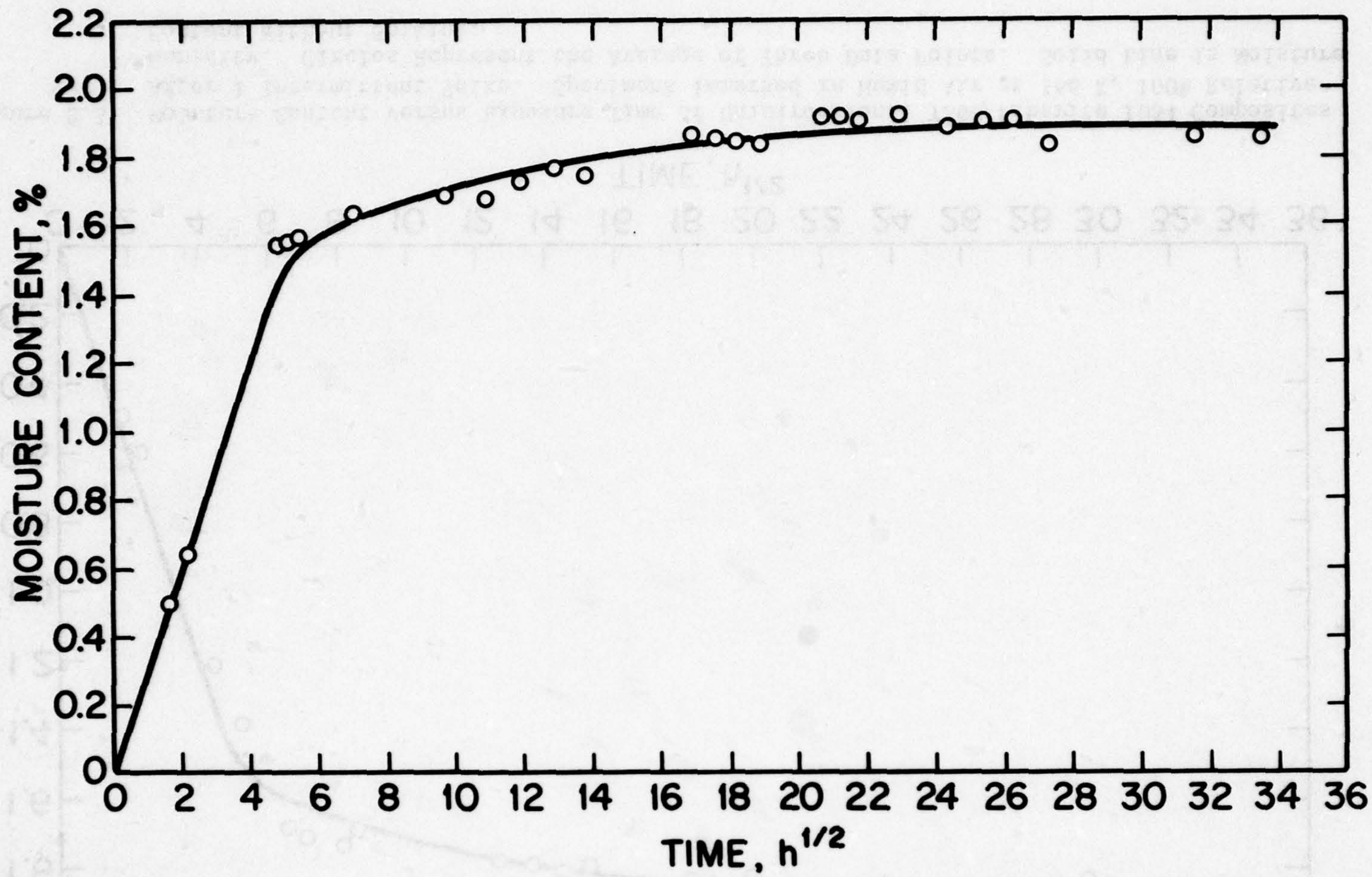

Figure B.2 Moisture Content Versus Exposure Time of Unidirectional T300/Fiberite 1034 Composites Remoisturized in 366 K Air at 100% Relative Humidity. Specimens were Preconditioned in 366 K Air at 100% Relative Humidity Up to the Maximum Saturation Levels and Oven Dried Before Remoisturization. Circles Represent the Average of Three Data Points. Solid Line is Fit to Data.

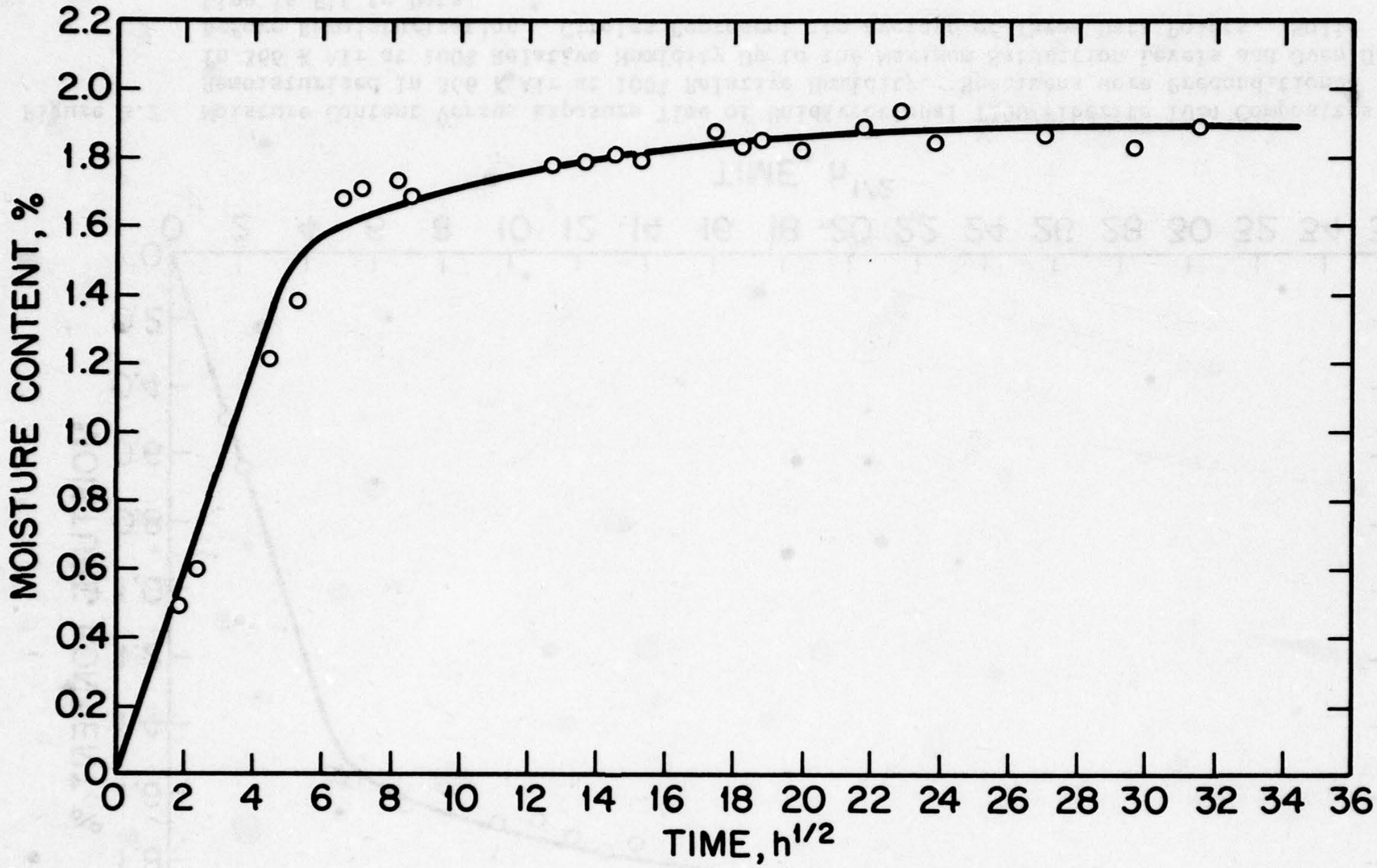

Figure B.3 Moisture Content Versus Exposure Time of Unidirectional T300/Fiberite 1034 Composites After 1 Intermittent Spike. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

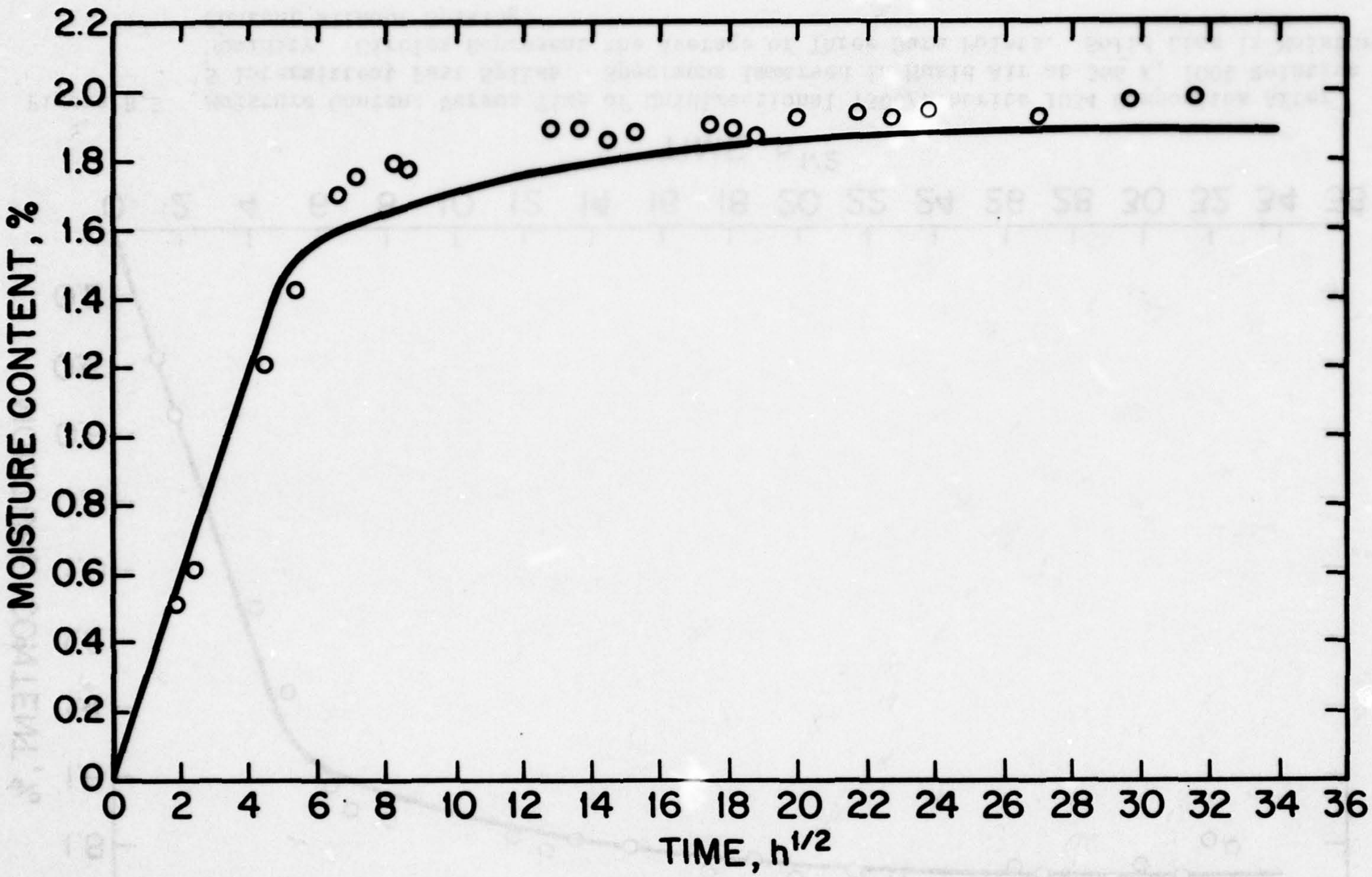

Figure B.4 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 2 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

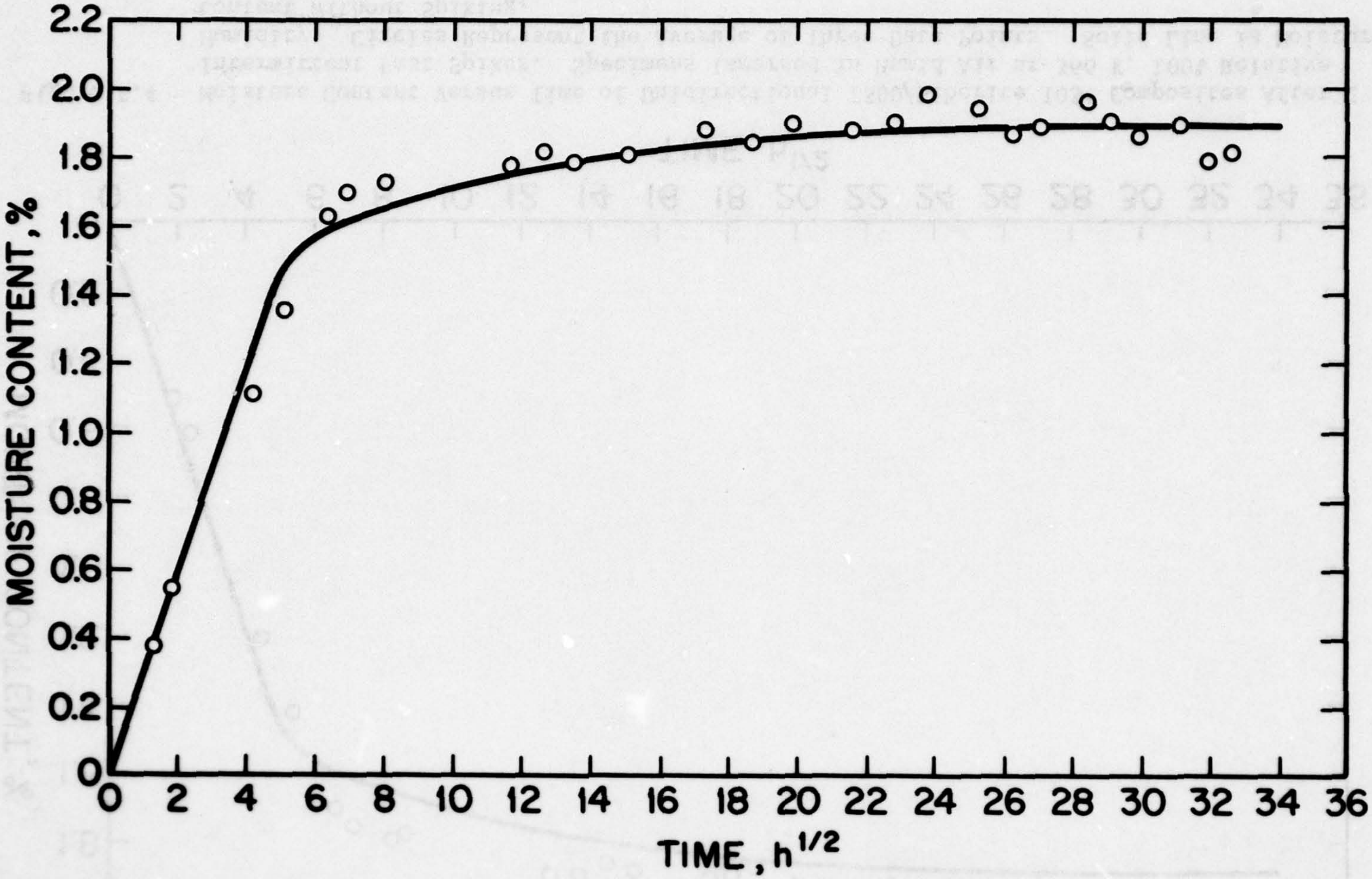

Figure B.5 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 5 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

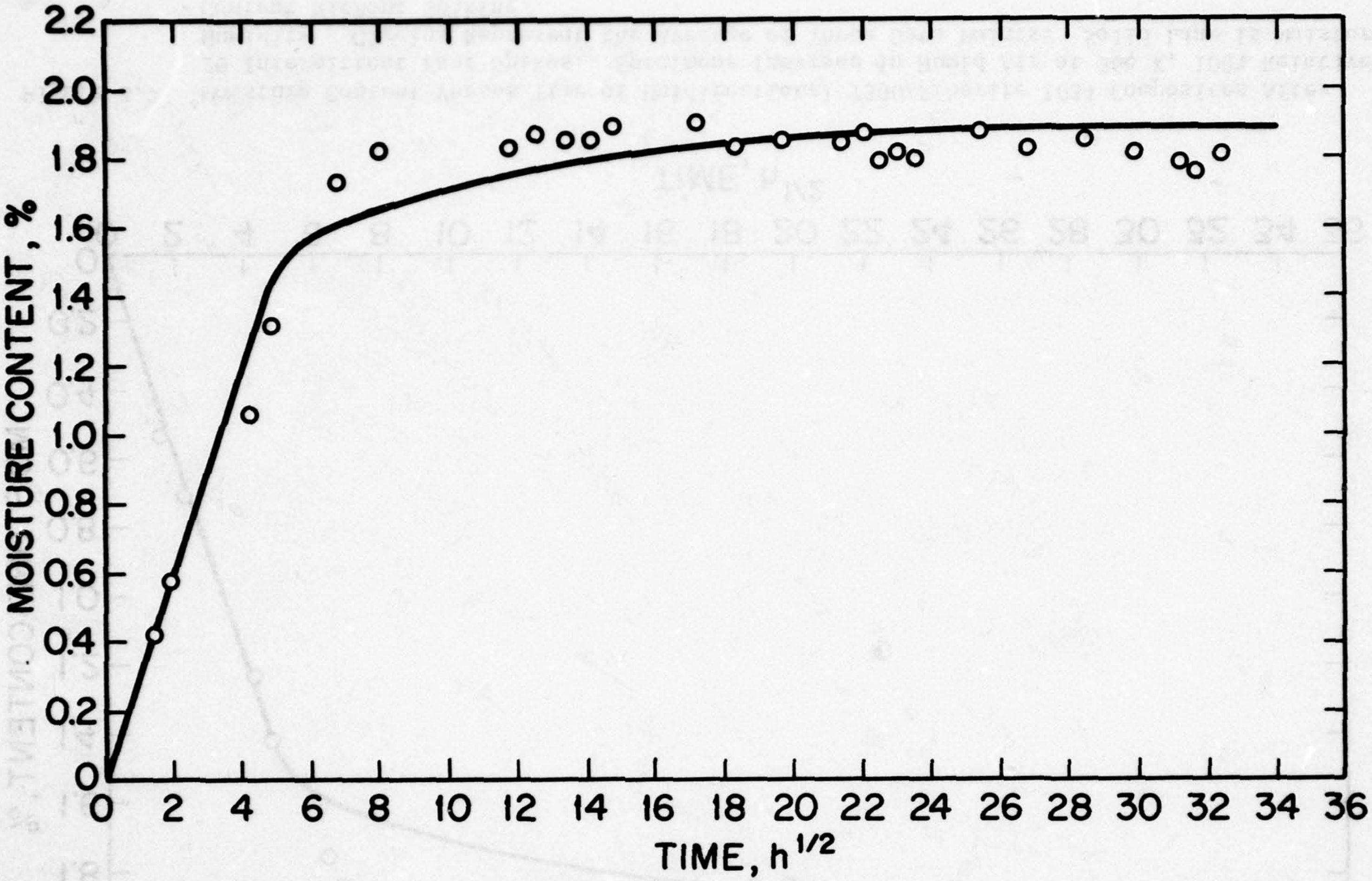

Figure B.6 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 10 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

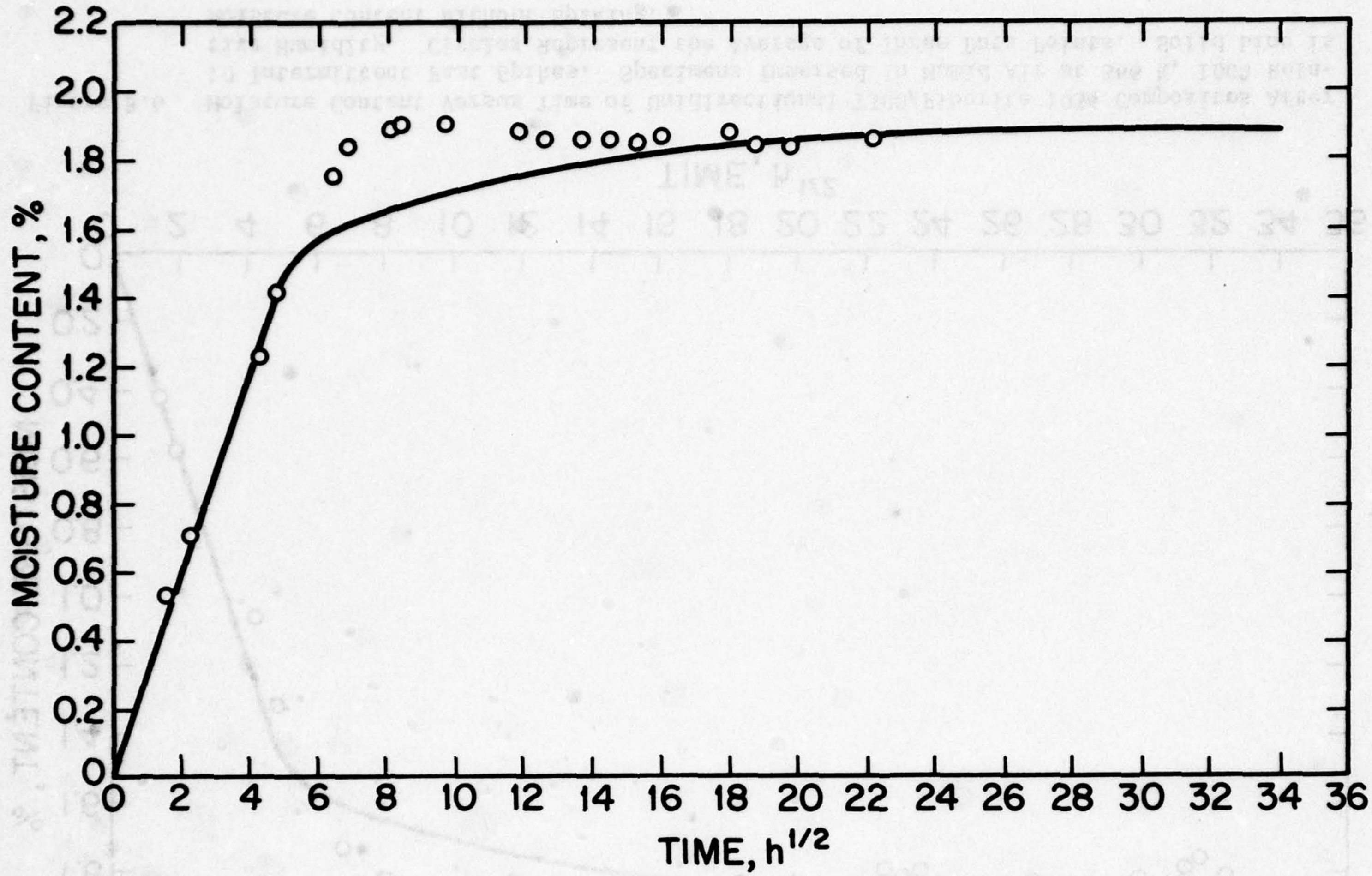

Figure B.7 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 20 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

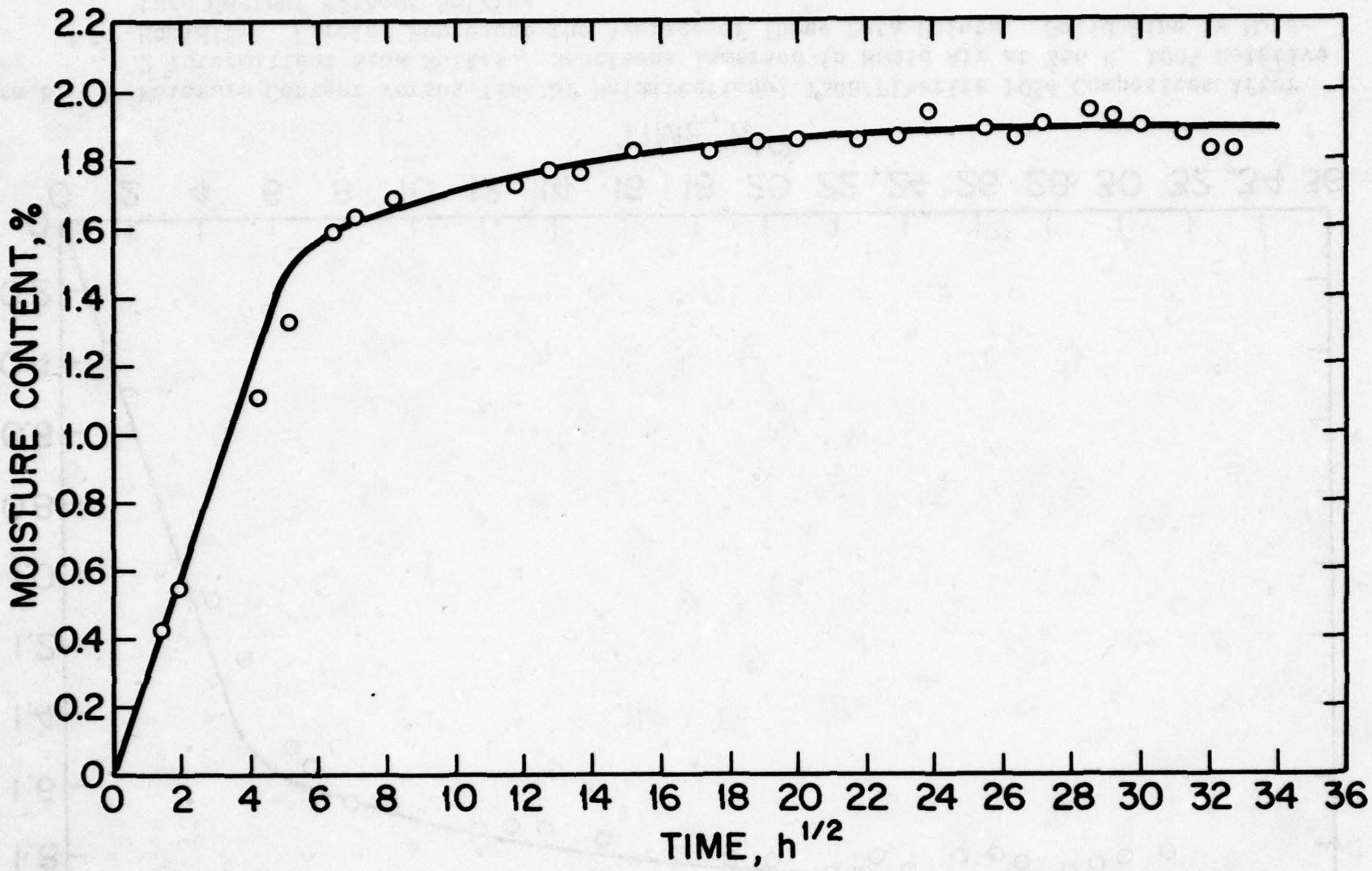

Figure B.8 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 1 Intermittent Slow Spike. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

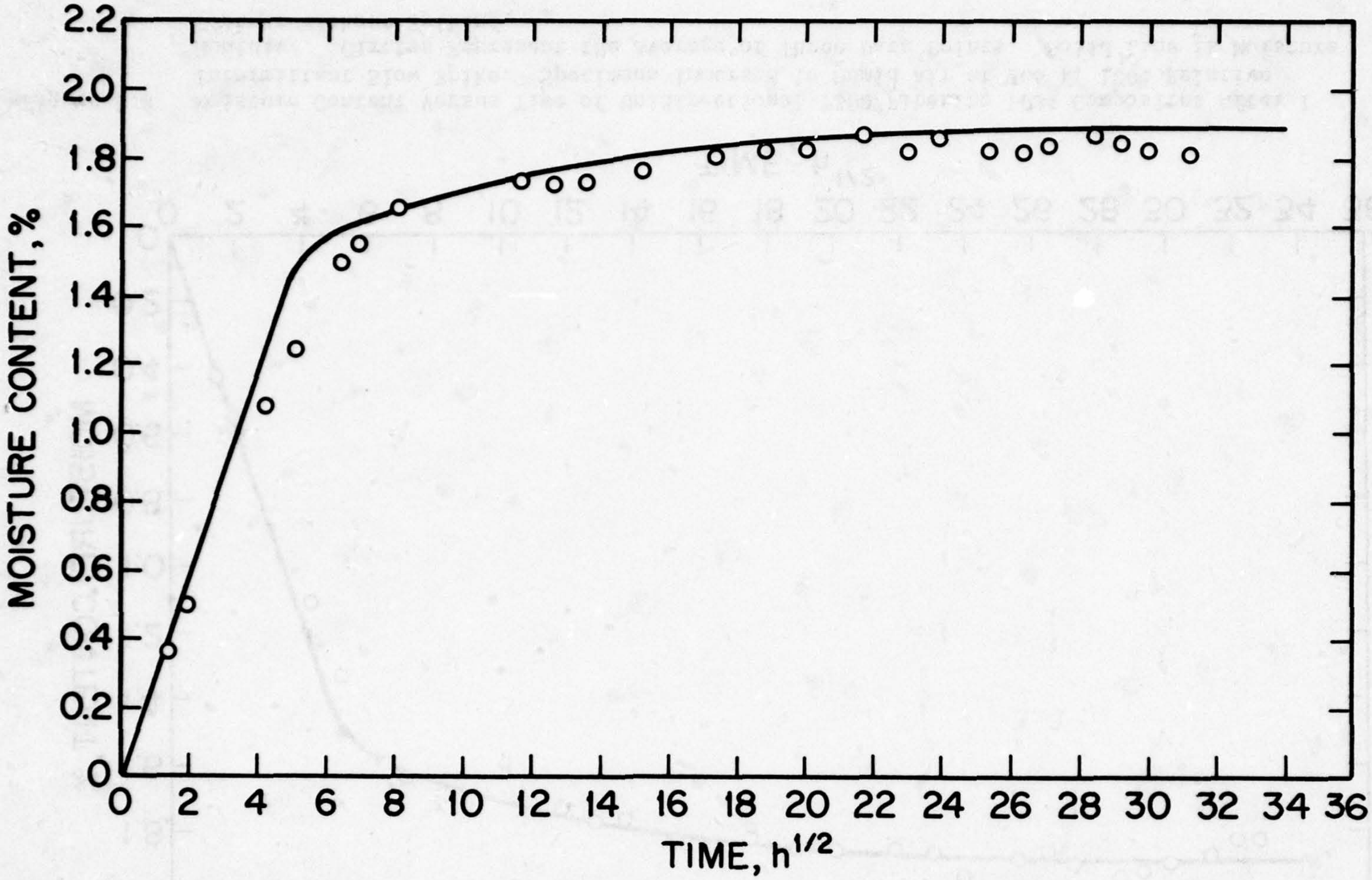

Figure B.9 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 2 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

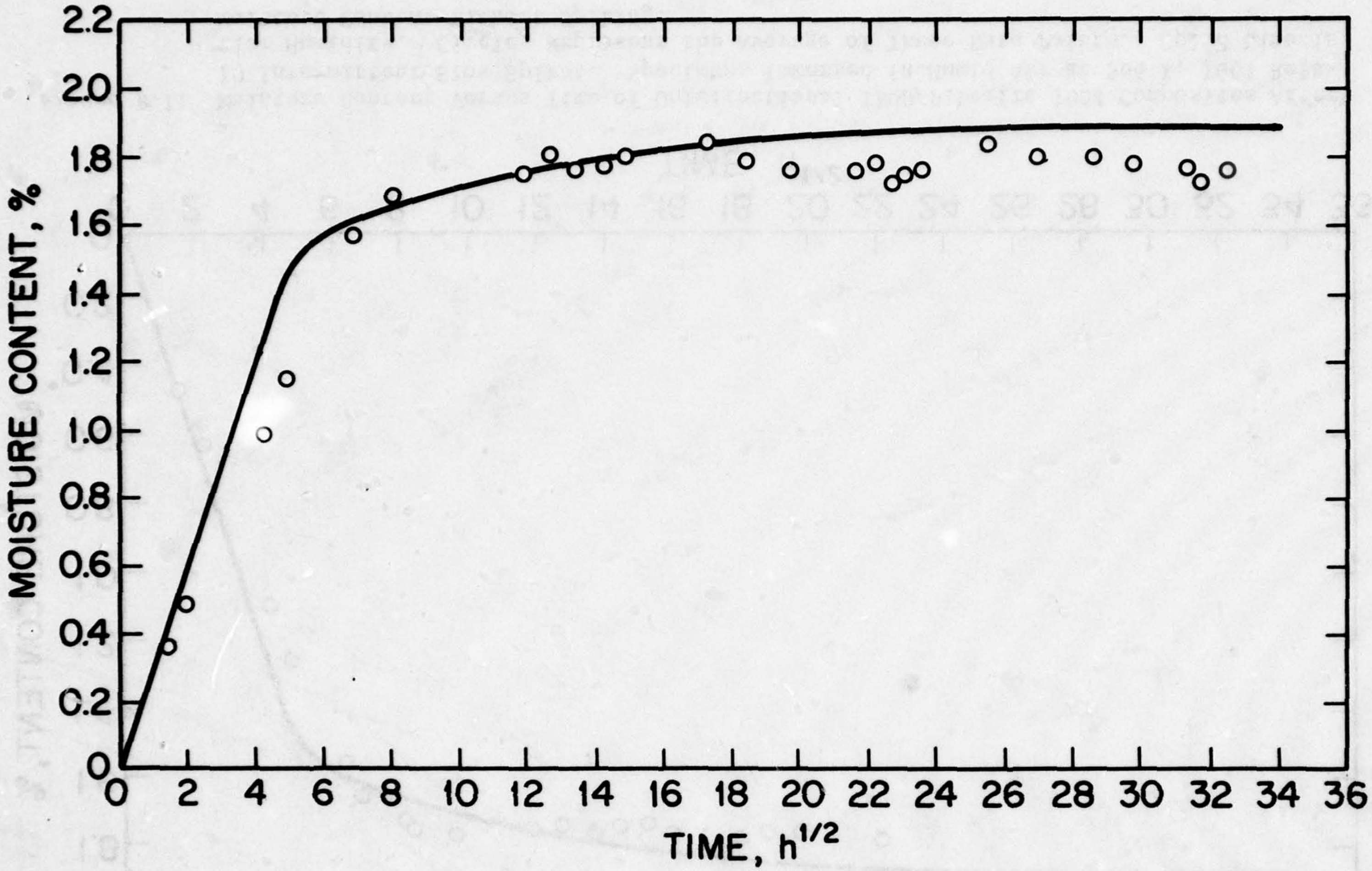

Figure B.10 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 5 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

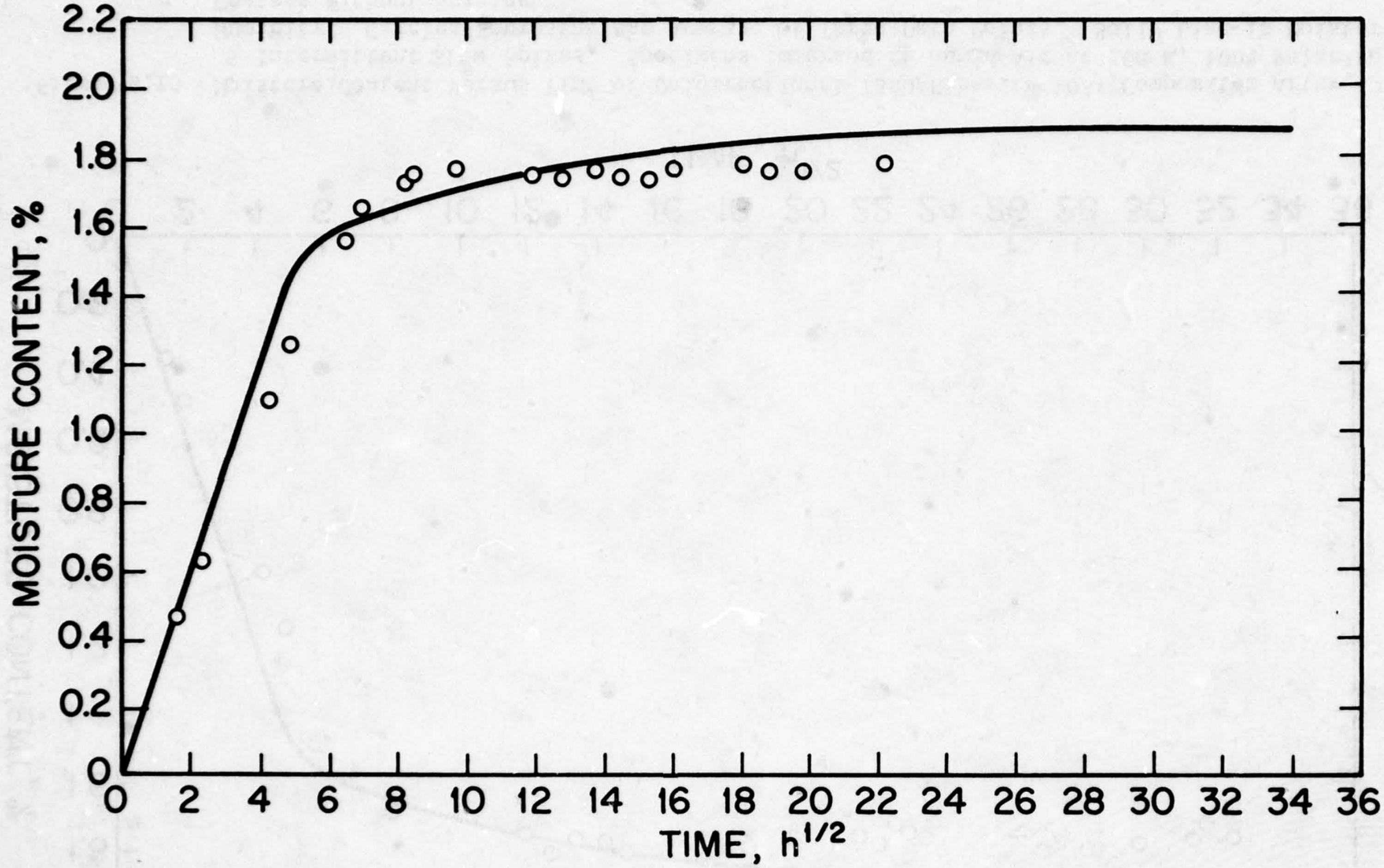

Figure B.11 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 10 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

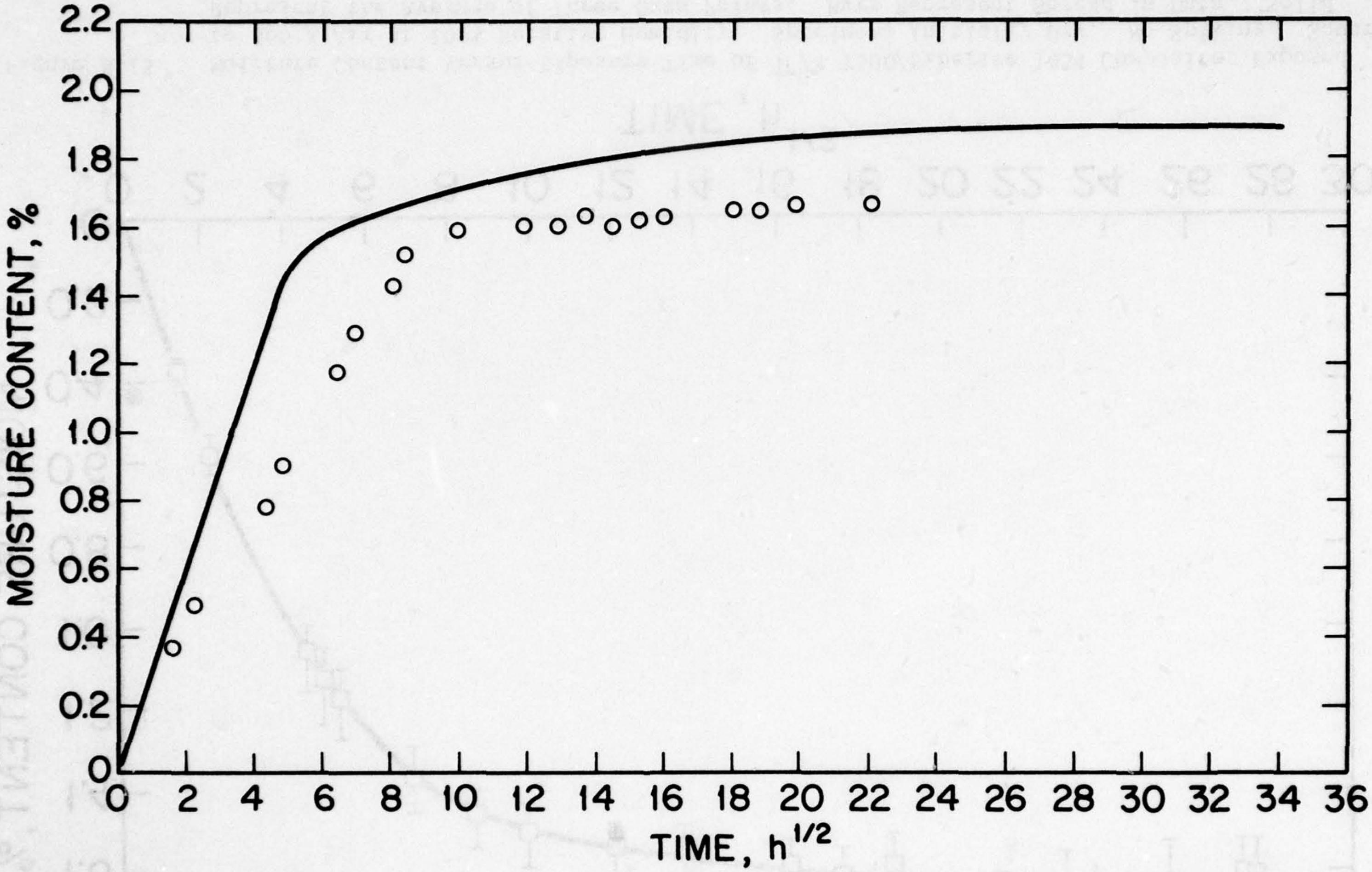

Figure B.12 Moisture Content Versus Time of Unidirectional T300/Fiberite 1034 Composites After 15 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Circles Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

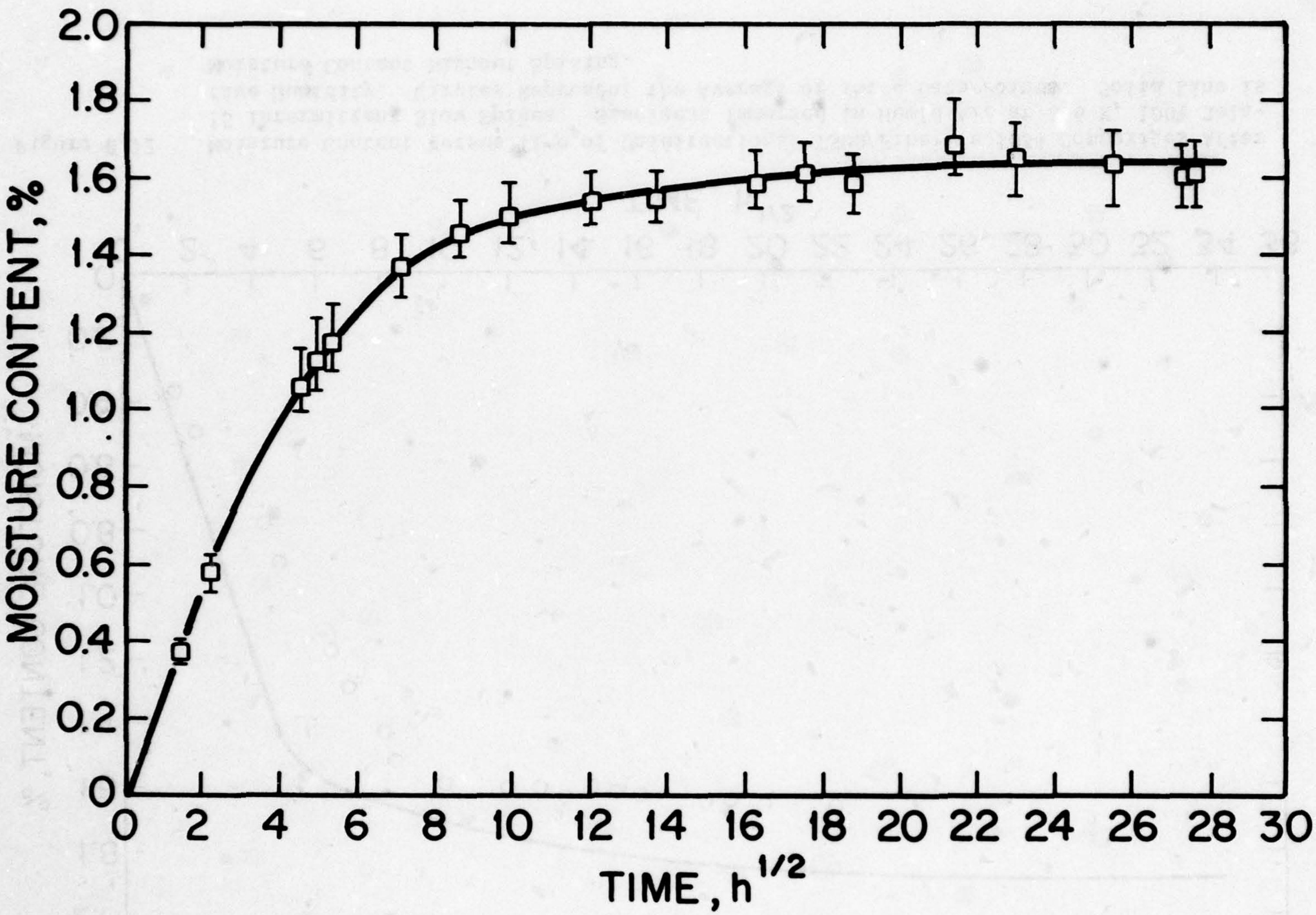

Figure B.13 Moisture Content Versus Exposure Time of $\pi/4$ T300/Fiberite 1034 Composites Exposed to 366 K Air at 100% Relative Humidity. Specimens Initially Dry. No Spiking. Squares Represent the Average of Three Data Points. Bars Represent Spread in Data. Solid Line is Fit to Data.

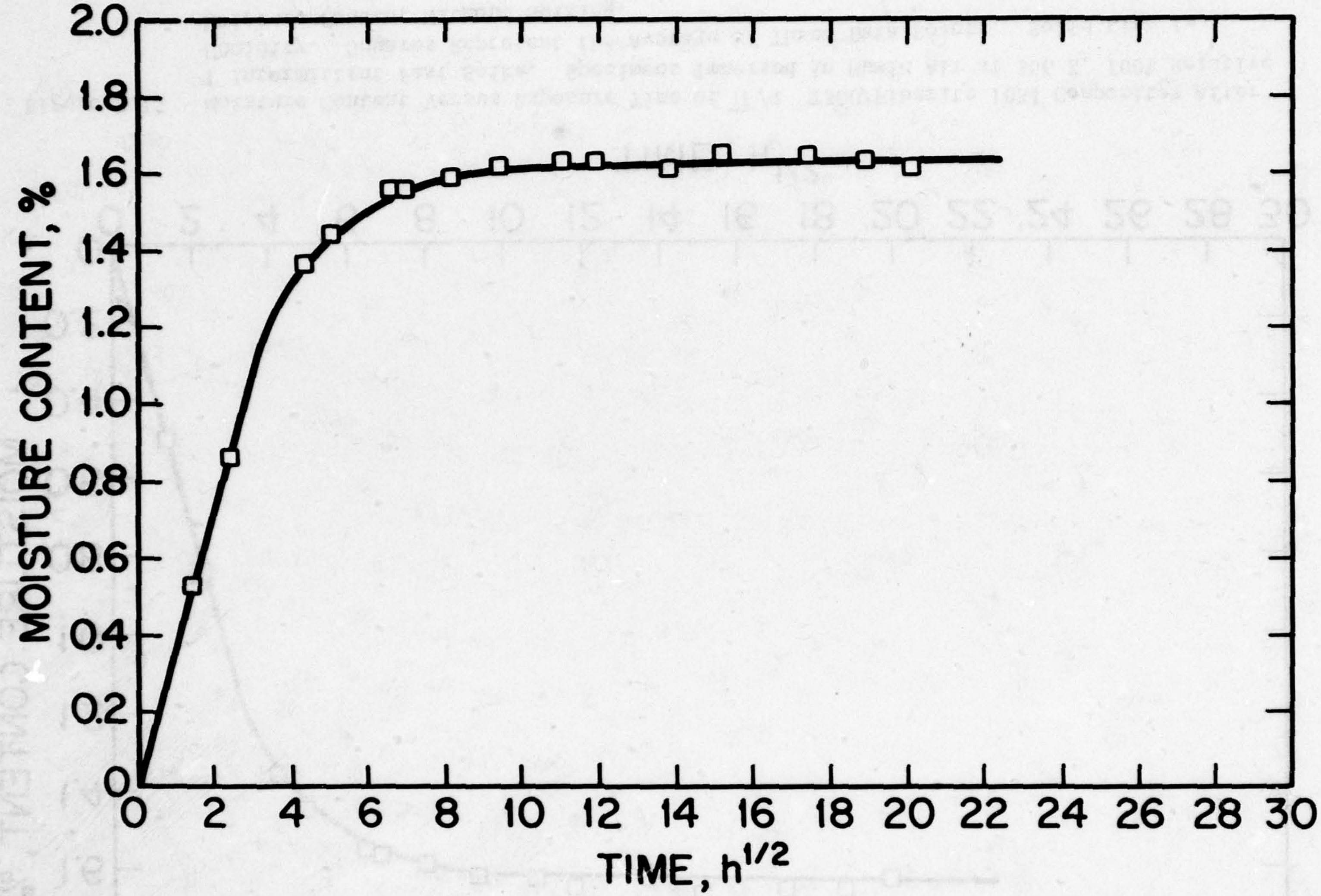

Figure B.14 Moisture Content Versus Exposure Time of $\pi/4$ T300/Fiberite 1034 Composites Remoisturized in 366 K Air at 100% Relative Humidity. Specimens Were Preconditioned in 366 K Air at 100% Relative Humidity Up to the Maximum Saturation Levels and Oven Dried Before Remoisturization. Squares Represent the Average of Three Data Points. Solid Line is Fit to Data.

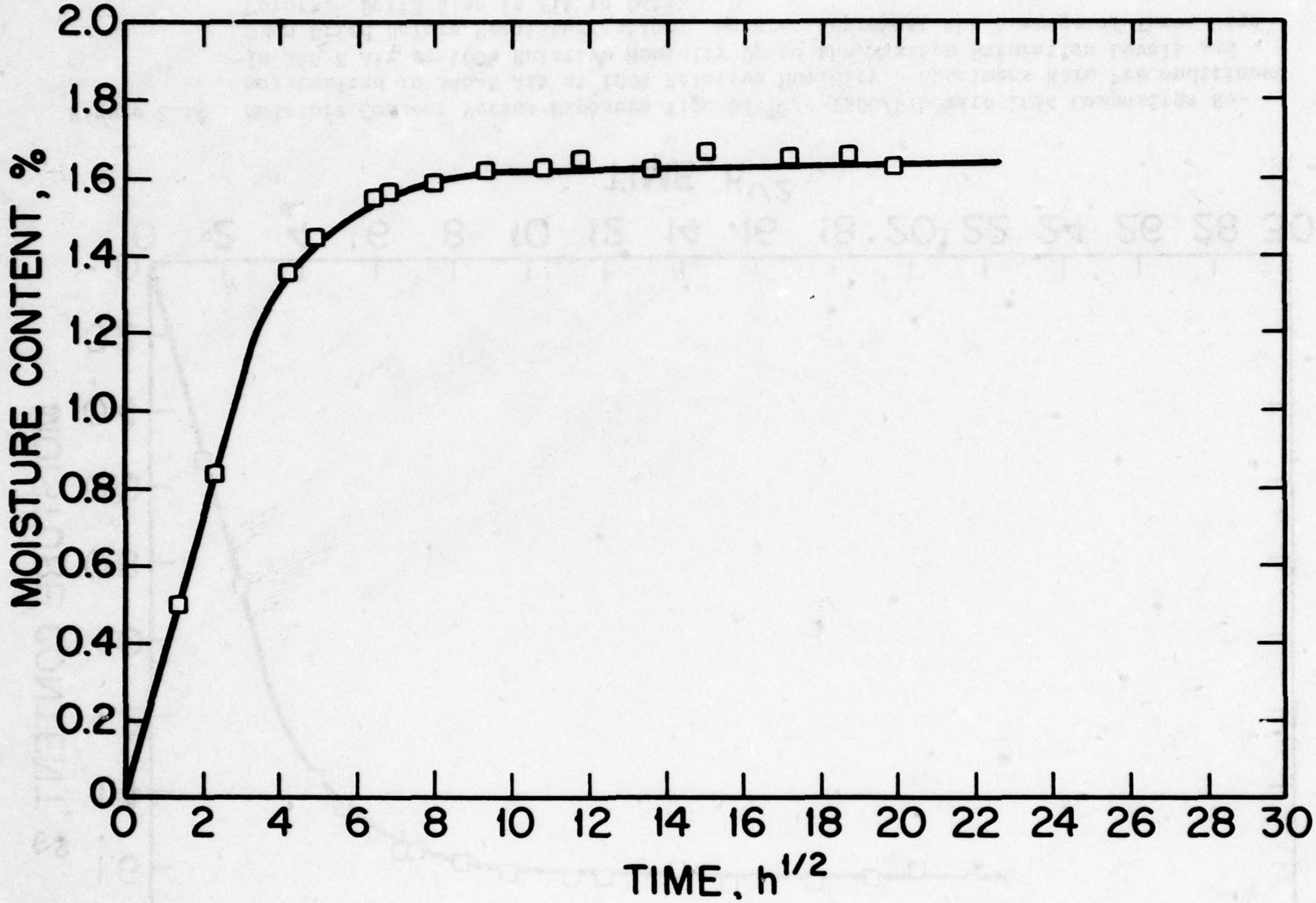

Figure B.15 Moisture Content Versus Exposure Time of $\pi/4$ T300/Fiberite 1034 Composites After 1 Intermittent Fast Spike. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

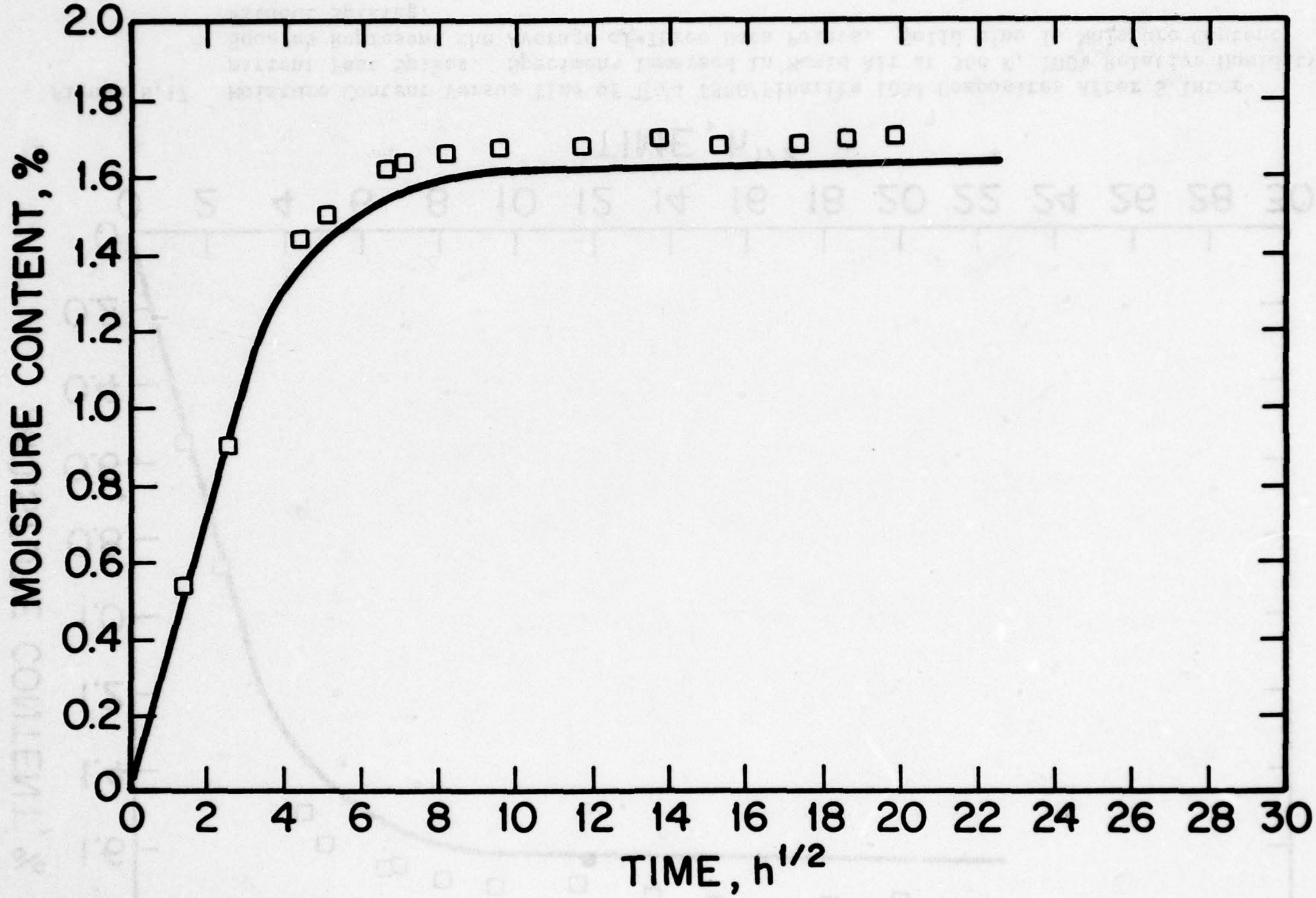

Figure B.16 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 2 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

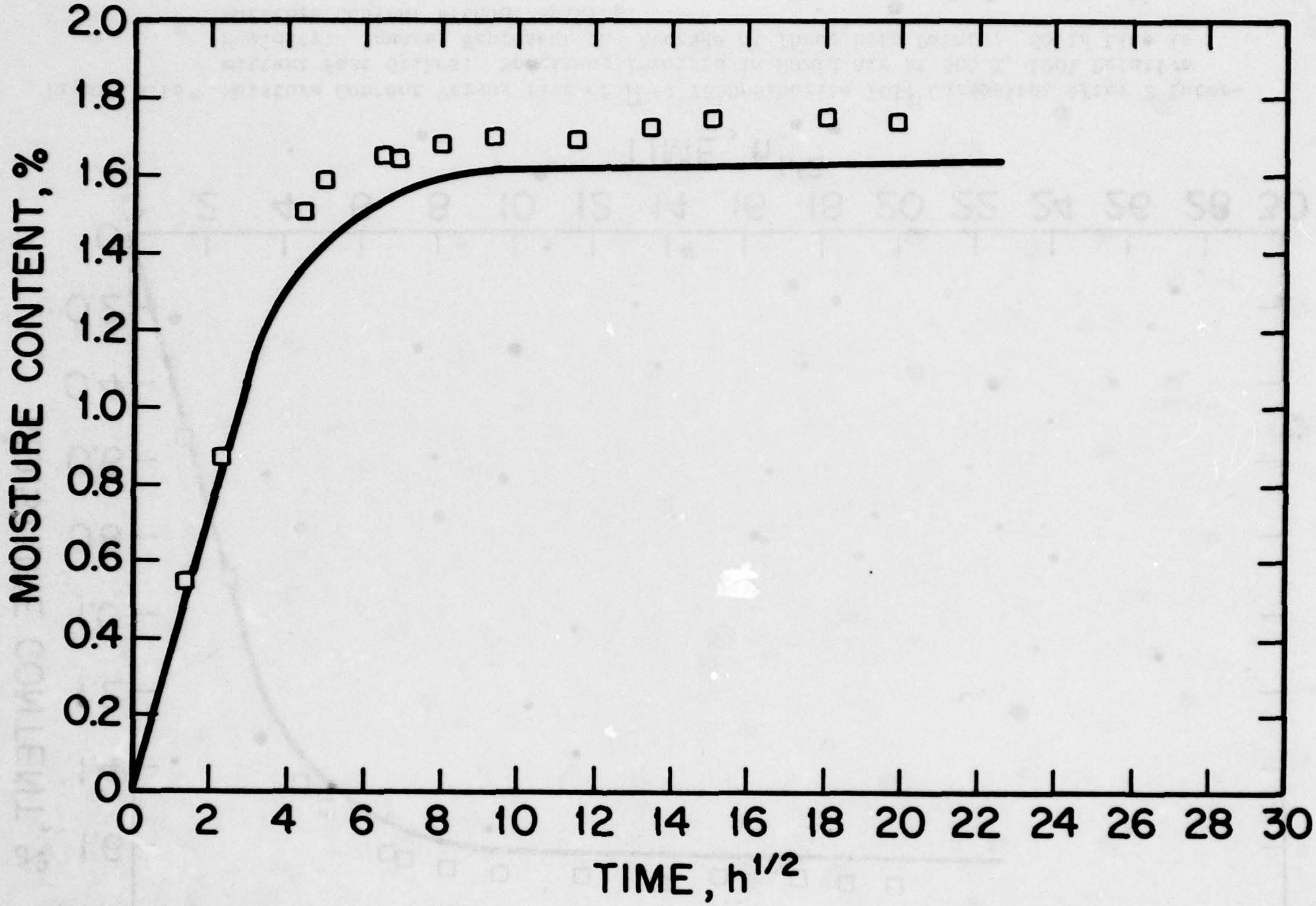

Figure B.17 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 5 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

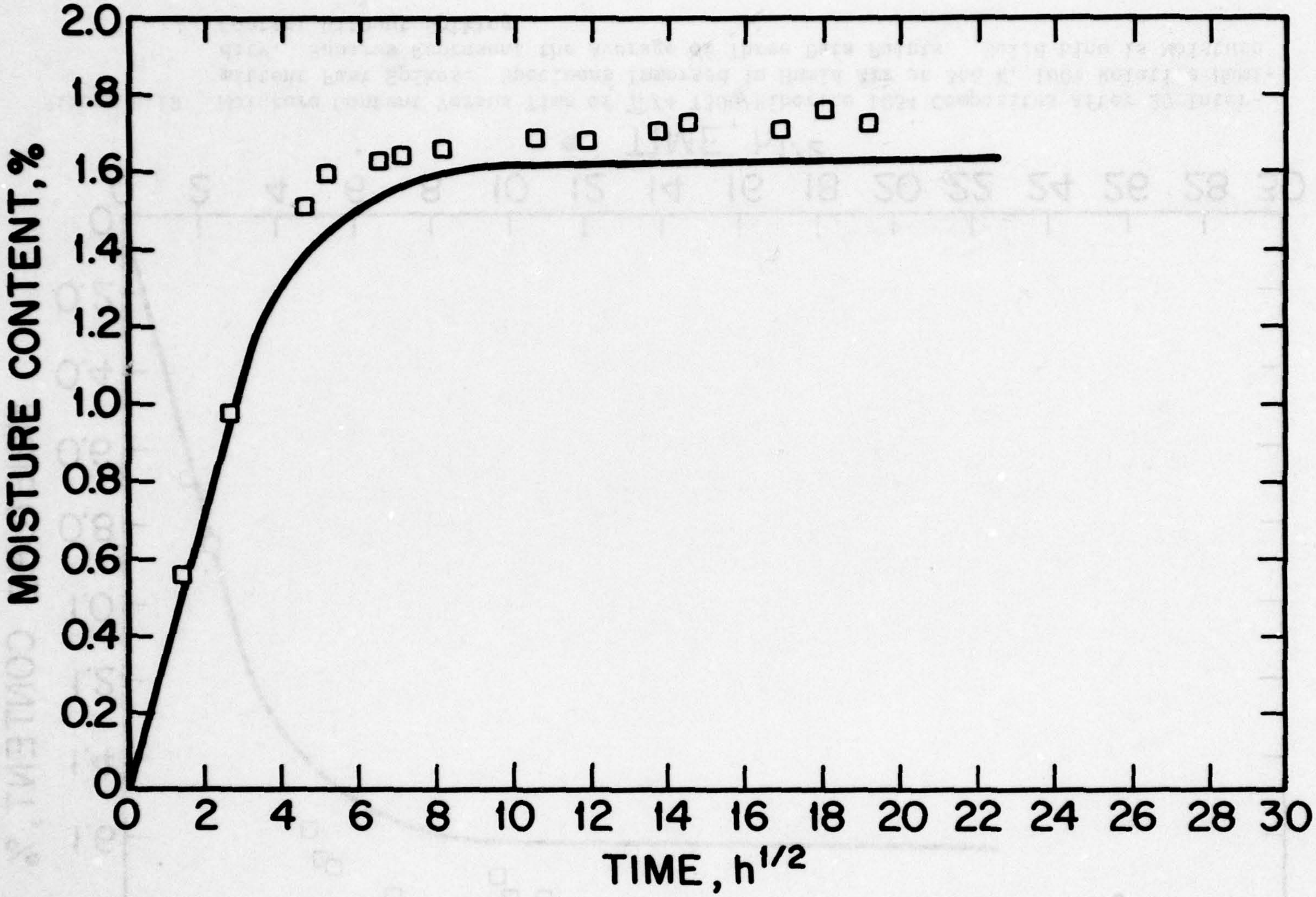

Figure B.18 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 10 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

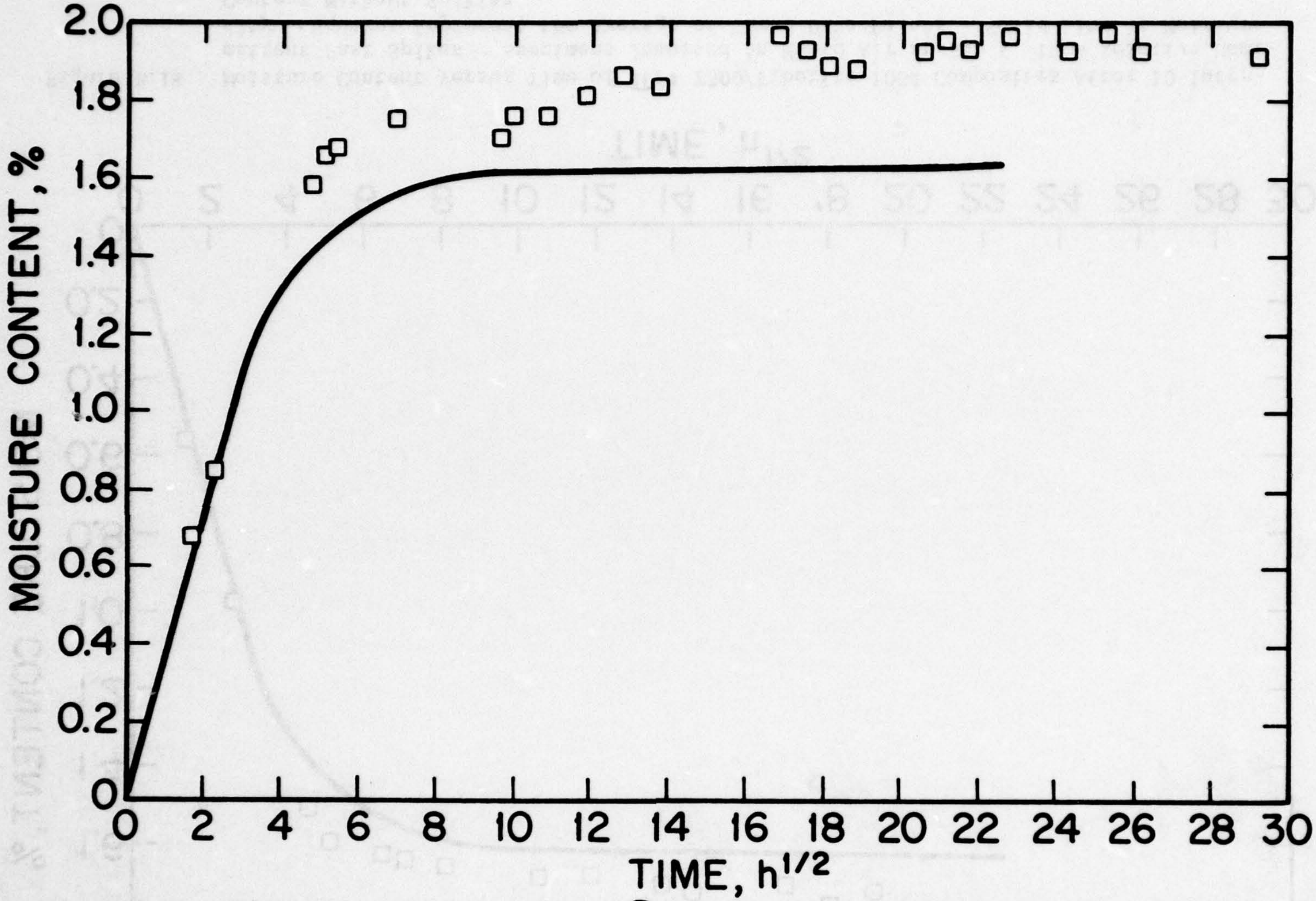

Figure B.19 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 20 Intermittent Fast Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

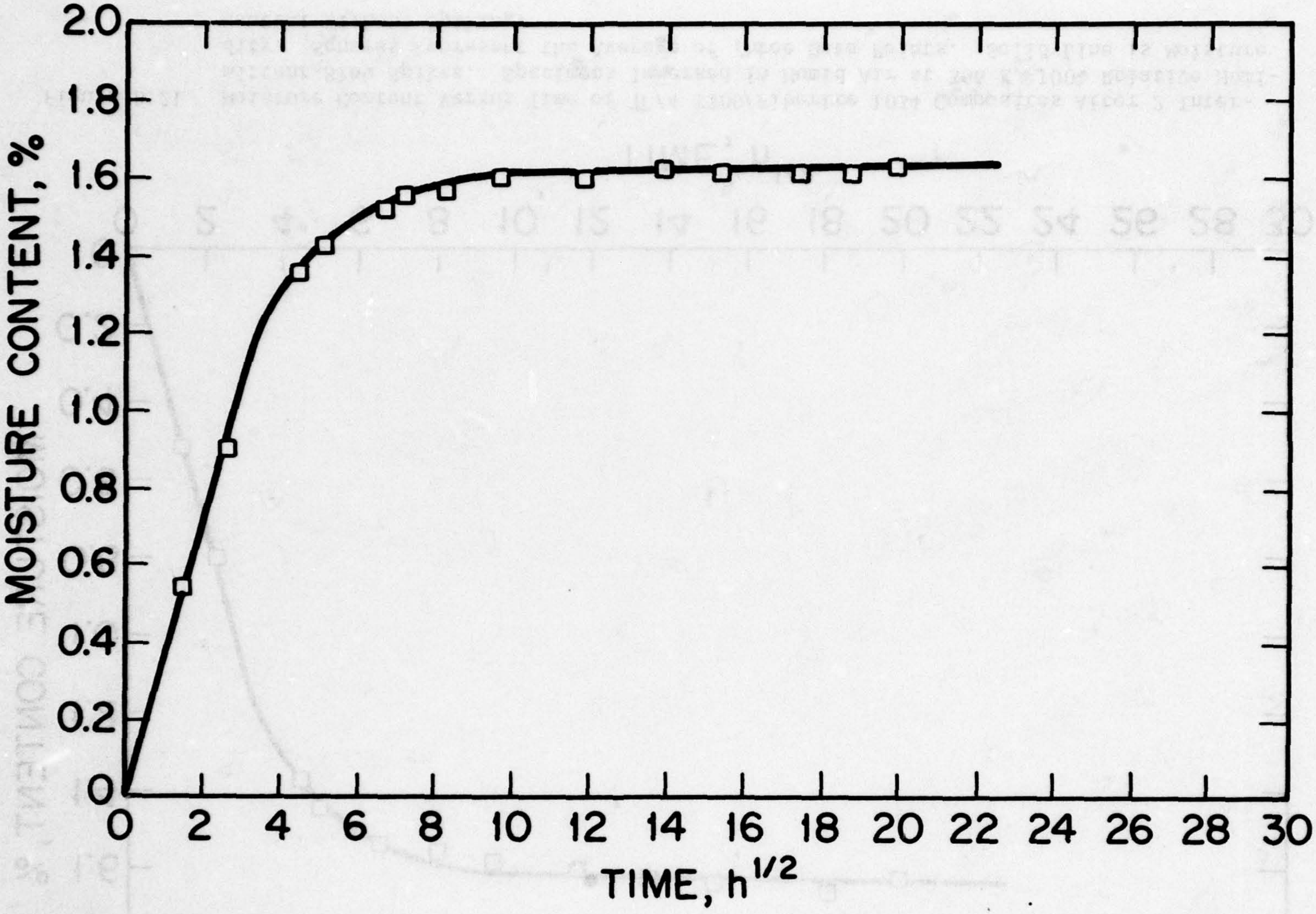

Figure B.20 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 1 Intermittent Slow Spike. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

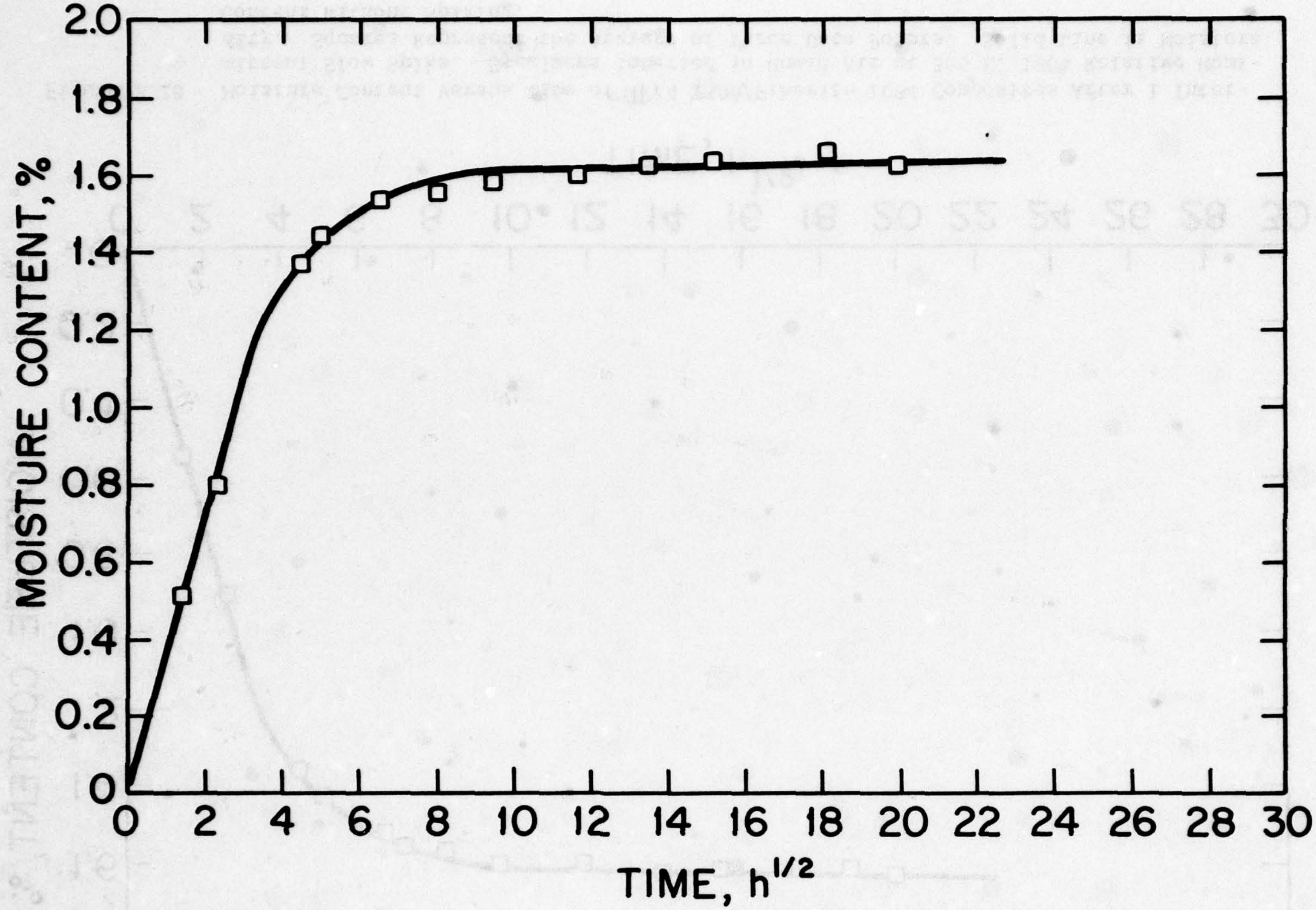

Figure B.21 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 2 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

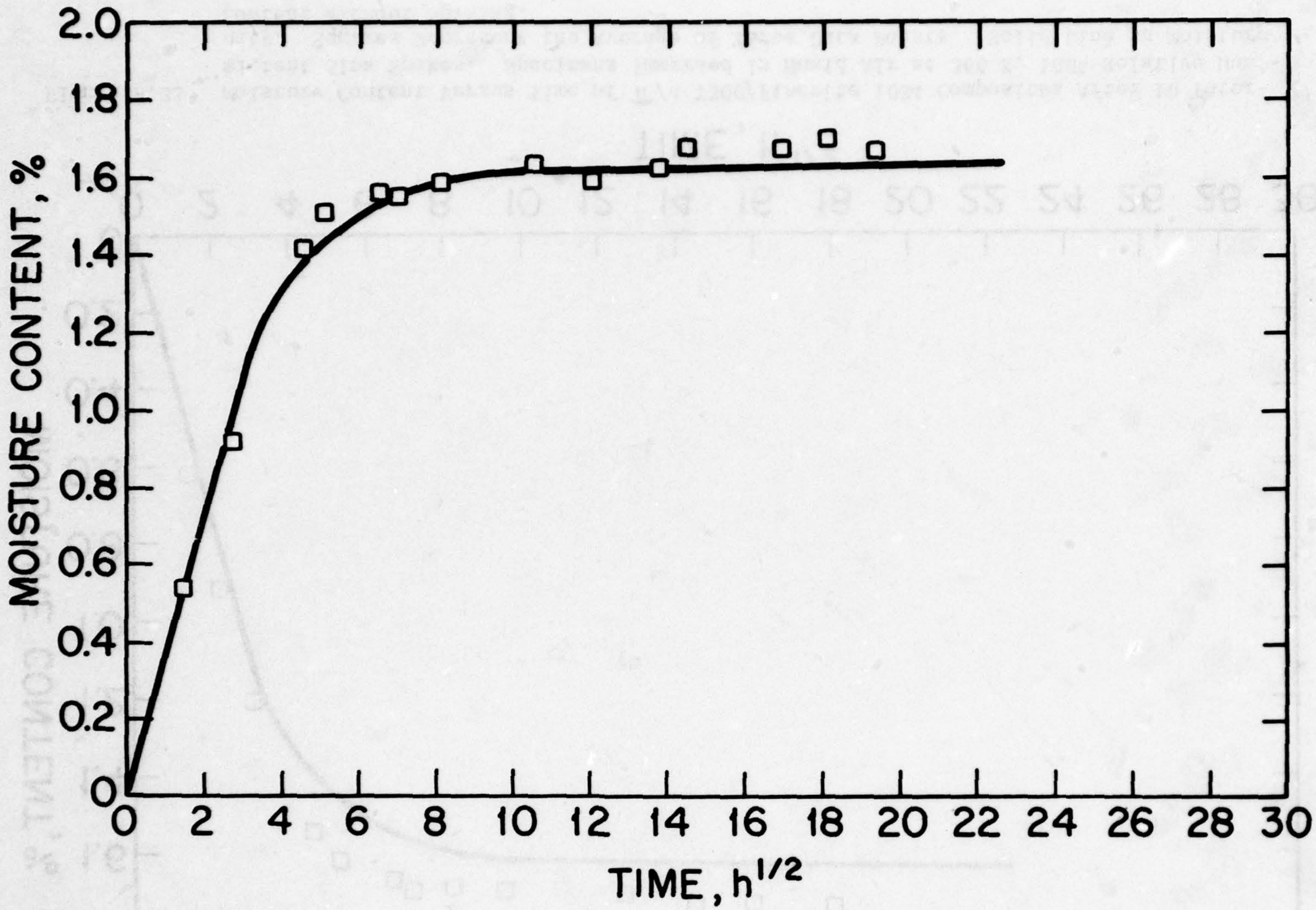

Figure B.22 Moisture Content Versus Time of π/4 T300/Fiberite 1034 Composites After 5 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

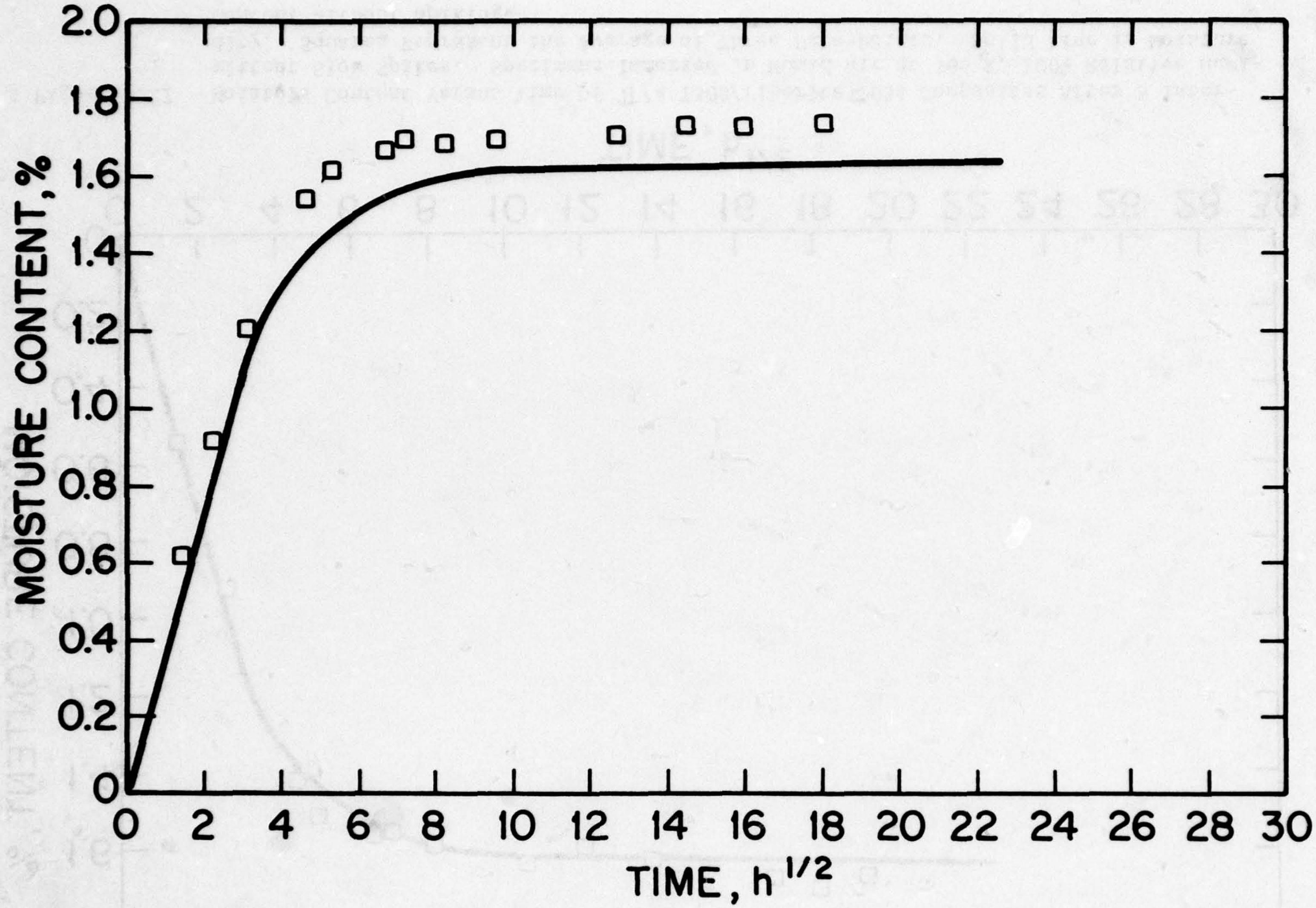

Figure B.23 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 10 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

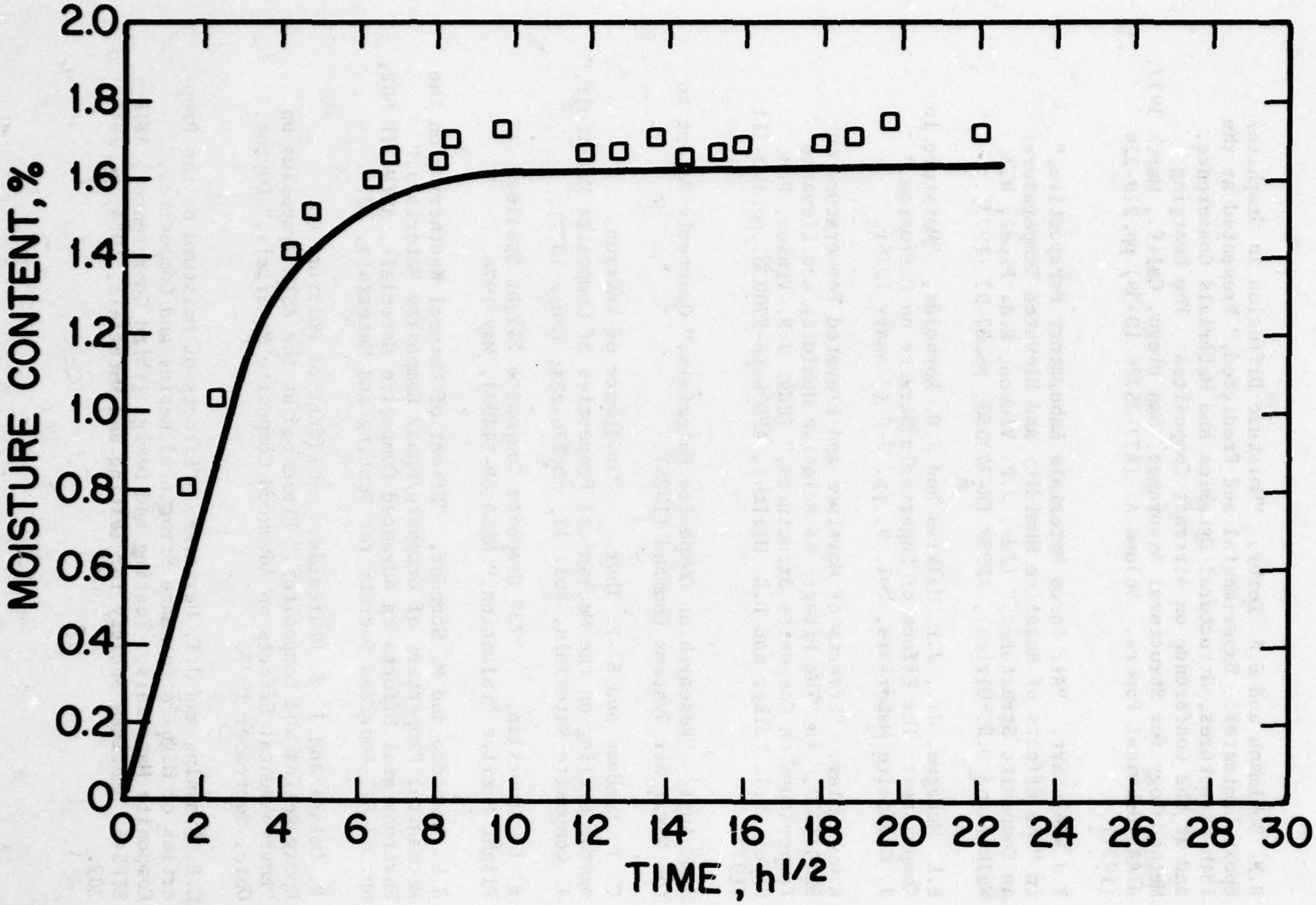

Figure B.24 Moisture Content Versus Time of $\pi/4$ T300/Fiberite 1034 Composites After 15 Intermittent Slow Spikes. Specimens Immersed in Humid Air at 366 K, 100% Relative Humidity. Squares Represent the Average of Three Data Points. Solid Line is Moisture Content Without Spiking.

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